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PHASE III REPORT

STUDY OF

INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

prepared
under contract for the

Federal-State
San Joaquin Valley
Drainage Program

OCTOBER 1989

This report presents the results of a study conducted for the Federal-State Interagency San Joaquin Valley Drainage Program. The purpose of the report is to provide the Drainage Program agencies with information for consideration in developing alternatives for agricultural drainage water management. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

The San Joaquin Valley Drainage Program was established in mid-1984 as a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the Program are to investigate the problems associated with the drainage of irrigated agricultural lands in the San Joaquin Valley and to formulate, evaluate, and recommend alternatives for the immediate and long-term management of those problems. Consistent with these purposes, Program objectives address the following key areas: (1) Public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources.

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Sacramento, California 95825-1898

PHASE III REPORT

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INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

Prepared for the

San Joaquin Valley Drainage Program
2800 Cottage Way, Room W-2143
Sacramento, CA 95825-1898

Under

U. S. Bureau of Reclamation
Contract No. 9-FC-20-07880

By

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Fresno, CA 93701

October 1989

SJVDP PHASE III REPORT
STUDY OF INNOVATIVE TECHNIQUES FOR DRAINAGE REDUCTION

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EXECUTIVE SUMMARY

PHASE III REPORT TO THE SAN JOAQUIN VALLEY DRAINAGE PROGRAM:

STUDY OF INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

The Phase III report summarizes results of a two year field study of irrigation management/controlled drainage techniques to reduce subsurface flows and constituent loads. For Phase III three west side fields were chosen for study. Field B10-2 was a 150 acre tomato field located in Broadview Water District. Field P-1 was a 93 acre tomato field located in Panoche Water District. Field W-3 was a 152 acre cotton field located in Westlands Water District.

Early in the 1989 season, the tile drainage system on Field B10-2 was modified by installing DOS-IR Valves to control the drainage outflow. During the previous season the field was monitored but no controlled drainage program was implemented. Irrigation and drainage monitoring data indicated that irrigation management and controlled drainage during 1989 resulted in limiting deep percolation to 1.9 inches. Upflux was calculated at 3.4 inches. Approximately 15% more salts and 12% more boron left the field in the drainage effluent than was applied through the irrigation water. This does not include addition of salts due to soil amendments. The salinity and boron levels were significantly lower during the 1989 season under controlled drainage than they were during the 1988 season without controlled drainage. The reason has not been determined. Salinity monitoring over the course of the 1989 season showed an apparent upward trend in salinity levels. This increase was determined not to be statistically significant. However, this apparent trend may represent the normal salinization that occurs over the course of the season for tomato crops under west side growing conditions.

Six additional DOS-IR Valves were installed in the tile system at mid-field of Field P-1 early in the 1989 season. Six valves were previously installed at the north field boundary in 1988. The additional valves were needed to provide additional water table control. During the 1989 installation it was decided to effectively shut off the tile system in order to keep the water table as high as possible. It was then planned to open the valves as the water table rose. However, the water table never rose above desirable limits and, therefore, the valve settings remained constant. The combination of irrigation and controlled drainage management techniques resulted in 3.8 inches of deep percolation and 2.6 inches of upflux. A statistical analysis indicated that there was no significant difference in salinity and boron levels between sampling dates over the course of the study.

Due to grower operational concerns for the season, and high water table conditions, the DOS-IR Valves could not be installed on Field W-3. This prevented implementation of actively controlled drainage management. However, some drainage control was effected by control of the sump pump. Lack of a tile discharge measuring point made it necessary to estimate tile flows based on deep percolation losses. These data indicated that 60% more salts and 10% more boron infiltrated with the irrigation water than left the field in the drainage effluent. Soil sample data from the autumns of '87, '88 and '89 showed a statistically significant increase in salinity and boron levels over this period. This is due to the continued recycling of tailwater and drainage effluent necessary due to the lack of a drainage outlet for these lands.

Installation criteria were developed for controlled drainage implementation. They focused on site selection and DOS-IR Valve installation. Proper installation can greatly improve the ability to control the water table and enhance the success of controlled drainage management.

For the study fields under controlled drainage/irrigation management it was determined that crop use of the water table was enhanced while there was not a significant impact on the soil salt balance. Currently there is not enough data to know with certainty if the salt balance can be maintained over one or more crop rotations. Further study is required to answer this question. Additionally, development of a predictive irrigation/drainage model suitable as a day to day management tool for west side conditions is necessary for widespread controlled drainage implementation.

PHASE III REPORT TO THE SAN JOAQUIN VALLEY DRAINAGE PROGRAM

INNOVATIVE TECHNIQUES TO REDUCE SUBSURFACE DRAINAGE FLOWS

I. INTRODUCTION

A. Study overview

This study was designed to develop irrigation management and water table control techniques that may be implemented on fields with subsurface tile drains to reduce the volume of drain effluent and its constituent load without reducing crop yields. The fields' salt balances as well as the tile effluent constituents were analyzed to determine the effect of these innovative techniques. The study sites are located in Broadview, Panoche and Westlands Water Districts on the westside of the San Joaquin Valley.

Typically crops grown in areas of perched water will draw part of their seasonal use from the water table. The amount used may vary from a few percentage points of the total seasonal ET (evapotranspiration) to more than 50%. Water table contribution to ET is controlled by many factors such as crop type, water table depth and quality and physical and chemical characteristics of the soil. The most critical element is the proximity of the active root system to the water table. This study endeavors to develop techniques that facilitate the control and management of this process in order to reduce both the volume of irrigation water and tile drainage water. This is especially important in light of disposal problems associated with drainage water in the San Joaquin Valley.

B. Program evolution

1. Phase I

Phase I of the study covers work done in Fiscal Year 1987 (ending on September 30, 1987). The first work item was to review existing literature on crop water use from a shallow water table, salt balance, leaching requirement, crop salt tolerance, irrigation and drainage water quality, drainage system design and geohydrology of the study area. Based on the literature search a drainage reduction scheme was proposed. A computer drainage model (DRAINMOD, developed by Dr. R.W. Skaggs of North Carolina State University) was then used to help evaluate several hardware and management scenarios that were thought to facilitate drainage reduction. The culmination of this work was to evaluate the potential for reducing subsurface drainage flows.

The idea of the DOS-IR Valve was solidified in Phase I. Figure 1. shows a DOS-IR Valve. It consists of a movable weir mounted in a fiberglass box with cutoff walls. The DOS-IR Valve is a key ingredient to this study. If a drainage system can be modified and operated such that the water table could be effectively controlled, the water table contribution to crop ET would be encouraged resulting in reduced drainage flows. The drainage water is normally viewed as more of a hinderance than a help; its disposal is a major environmental concern and has become an economic problem for agriculture. By adjusting the weir height in the DOS-IR Valves to shut off or reduce the flow from the tile system, the water table could be raised uphill of the control point. The strategy in operating the DOS-IR Valves is to maintain a water table level that will encourage crop use of the water table while ensuring adequate root zone aeration.

2. Phase II

During the cropping season of 1988, Phase II initiated field implementation of the irrigation management/controlled drainage techniques. Two fields in the Panoche Water District (P-1 and P-2) and one field in the Broadview Water District (B10-2) were selected. Two of the fields were planted to cotton and the other to melons. These fields were selected for the following reasons: They all appeared to have tile drain systems that worked and were in reasonable condition; they all had outlets for the drain water; they had typical San Joaquin Valley cropping patterns and the growers were willing to have their tile systems modified.

On Fields P-1 and P-2 DOS-IR Valves were installed as indicated in Figures 2 and 3. Field B10-2 (Figure 4) was left uncontrolled but a DOS-IR Valve was inserted in the collector line as control to enable separating out the tile flow from an adjacent field. Fields P-1 and B10-2 showed good potential for implementation of an irrigation management/controlled drainage program. However, Field P-2 had soils with very high intake rates, relatively steep field slope and a highly fluctuating water table. This made program implementation inadvisable. This field was eliminated from the program and the DOS-IR valves were removed from the field in February 1989.

3. Phase III

Phase III of this study was conducted during the 1989 cropping season. This phase of the study saw additional DOS-IR Valves installed on Fields P-1 and B10-2 (Figures 5 & 6). The DOS-IR

DOS-IR Valve

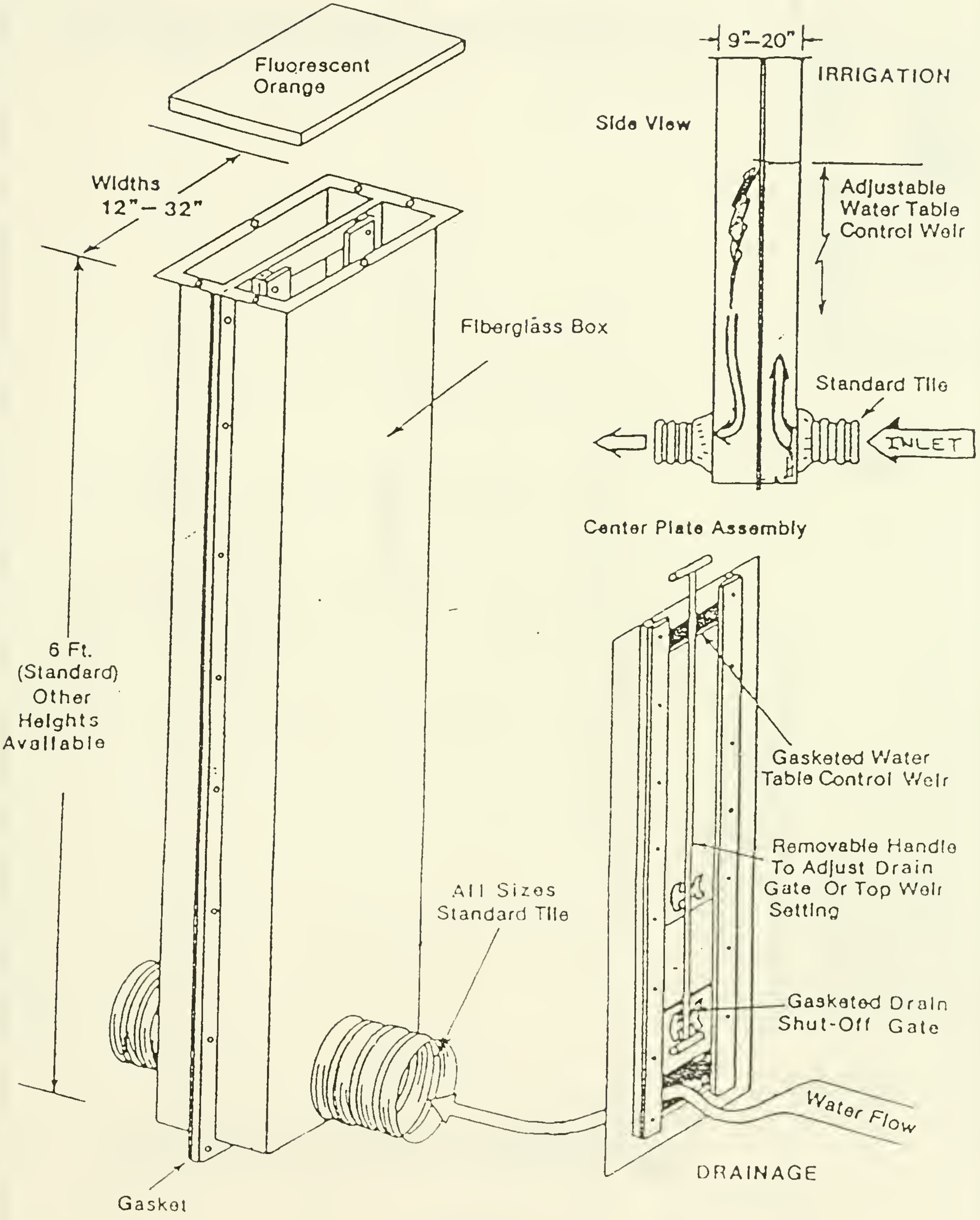

Fluorescent Orange
Widths 12" – 32"
6 Ft. (Standard) Other Heights Available
Fiberglass Box
Gasket
All Sizes Standard Tile
9"–20"
IRRIGATION
Side View
Adjustable Water Table Control Weir
Standard Tile
INLET
Center Plate Assembly
Gasketed Water Table Control Weir
Removable Handle To Adjust Drain Gate Or Top Weir Setting
Gasketed Drain Shut-Off Gate
Water Flow
DRAINAGE

Figure 1

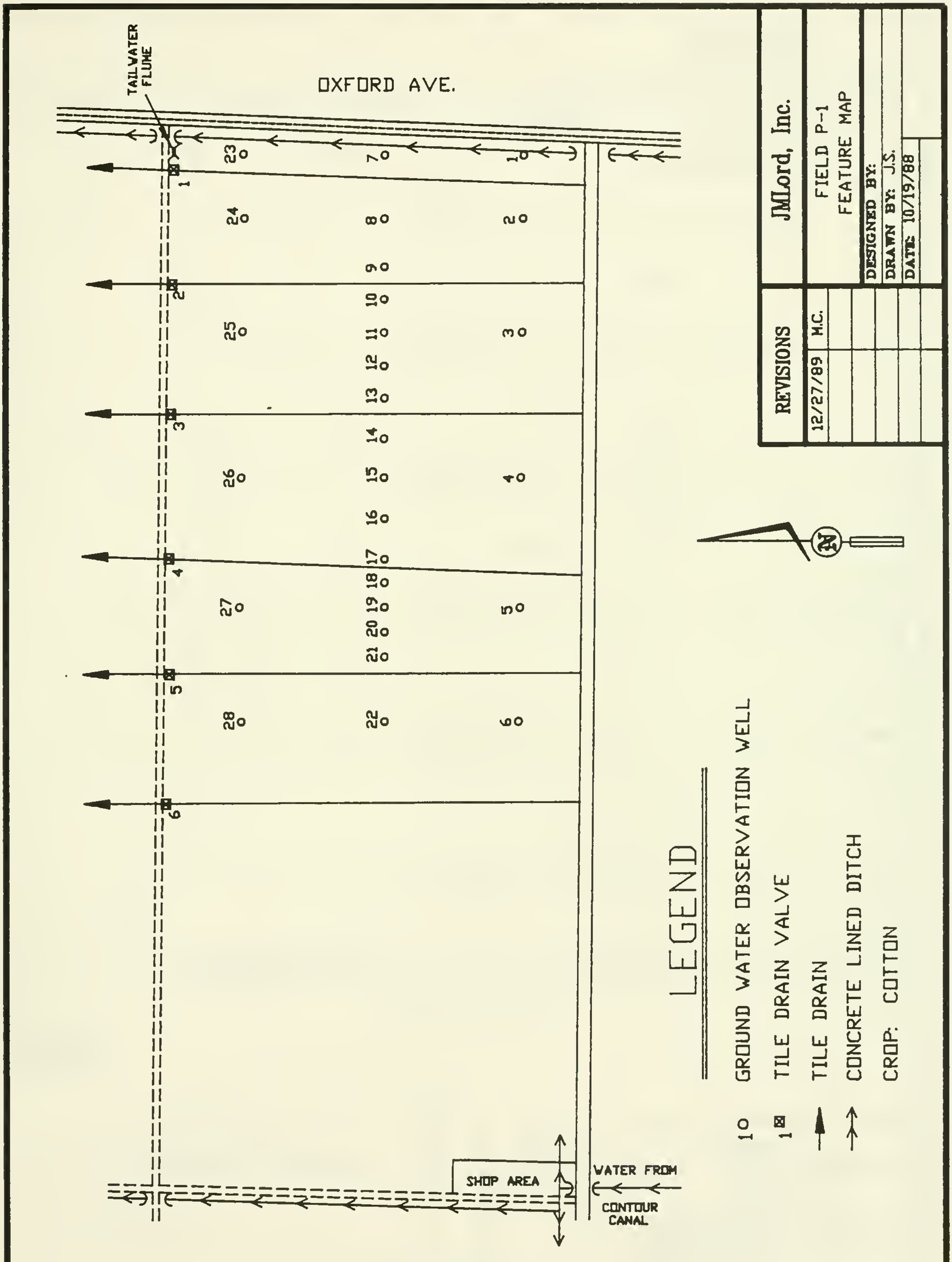

OXFORD AVE.
TAILWATER FLUME
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
SHOP AREA
WATER FROM CONTOUR CANAL
N
LEGEND
GROUND WATER OBSERVATION WELL
TILE DRAIN VALVE
TILE DRAIN
CONCRETE LINED DITCH
CROP: COTTON
JMLord, Inc.
FIELD P-1
FEATURE MAP
DESIGNED BY:
DRAWN BY: J.S.
DATE: 10/19/88
REVISIONS
12/27/89
M.C.

Figure 2

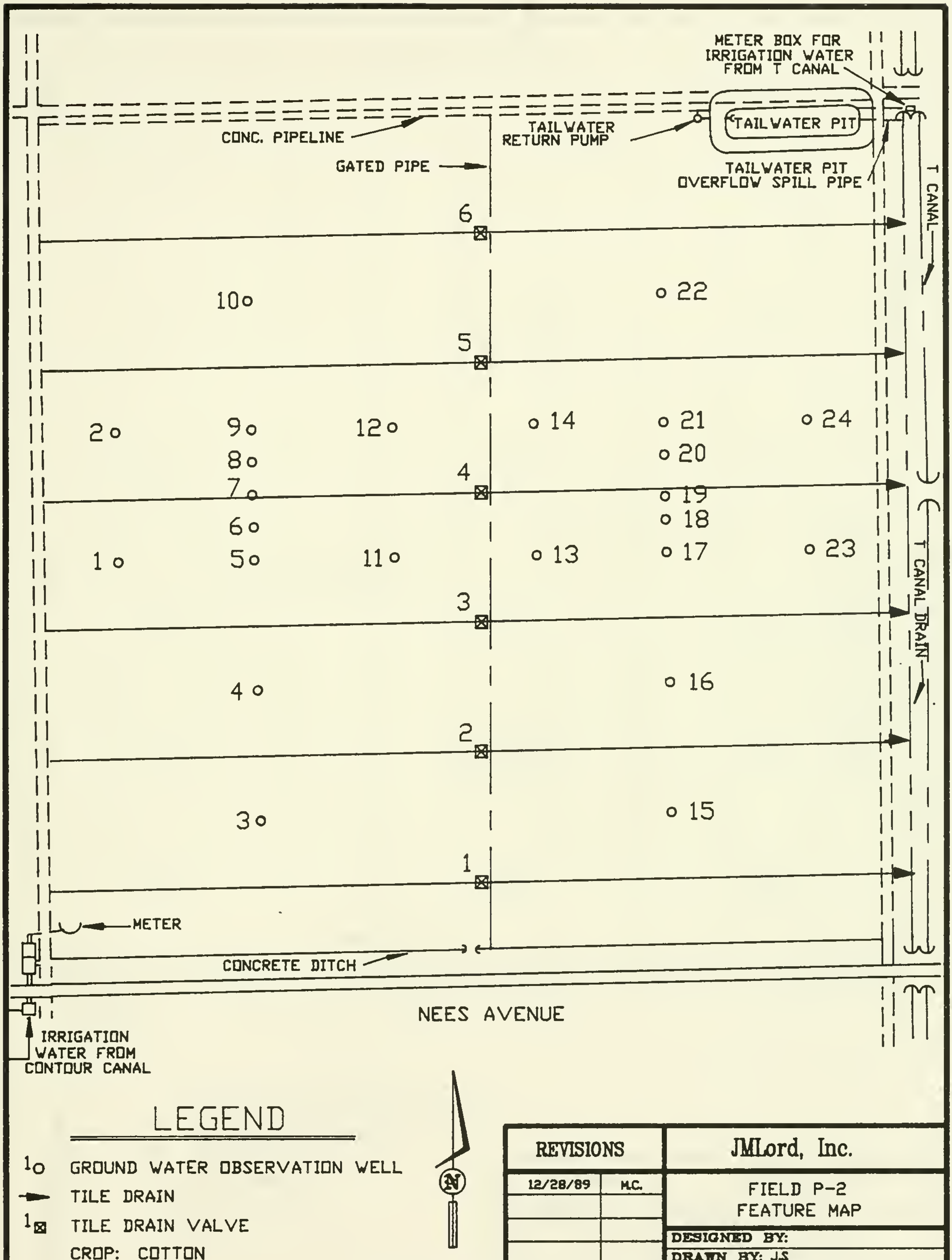
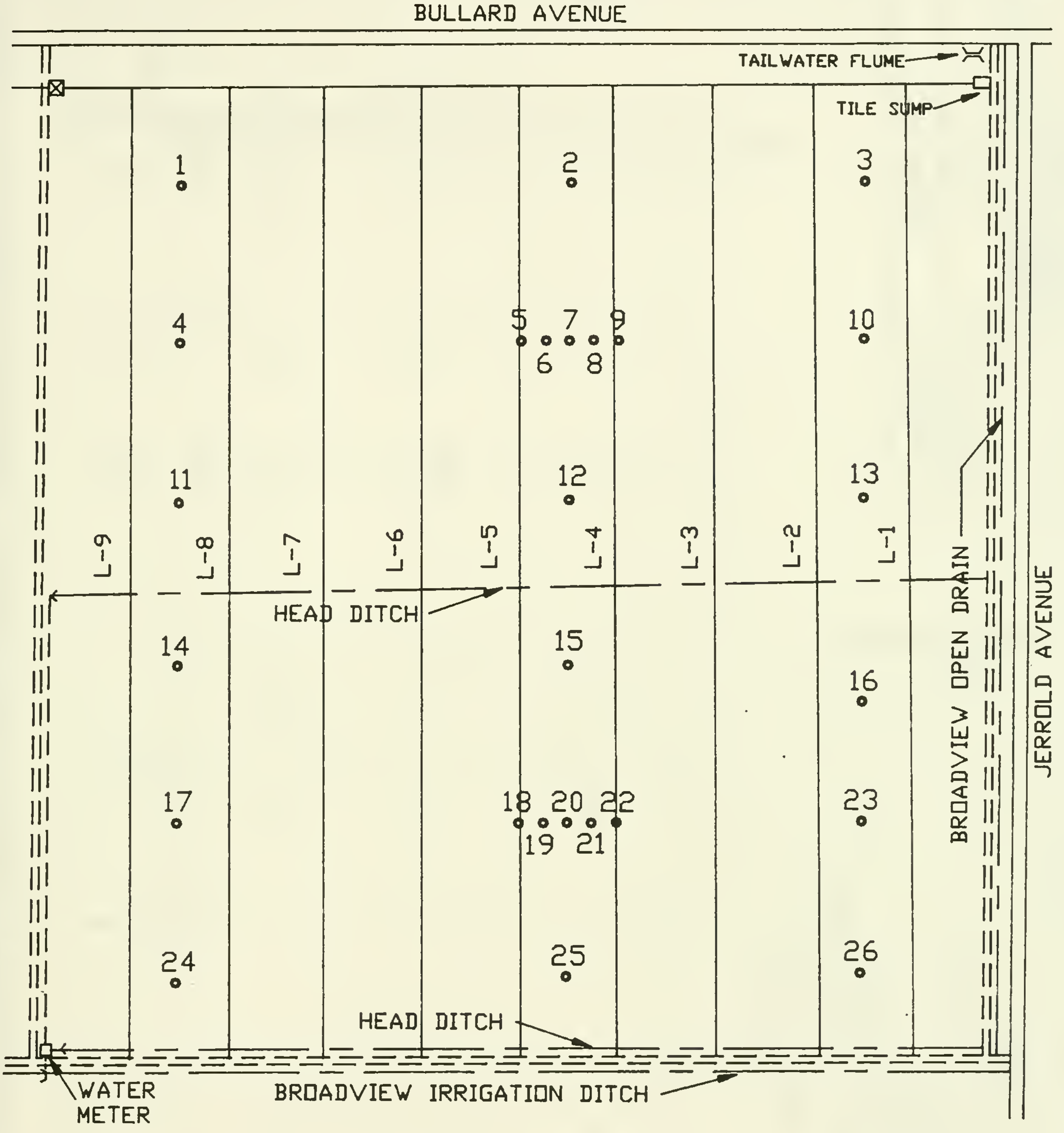


Figure 3

REVISIONS		JMLord, Inc.
12/28/89	M.C.	FIELD P-2 FEATURE MAP
		DESIGNED BY:
		DRAWN BY: J.S
		DATE: 10/14/88



LEGEND

- ^{1}● GROUND WATER OBSERVATION WELL
- ▣ TILE DRAIN VALVE
- — TILE DRAIN
- CROP: MELONS

REVISIONS		JMLord, Inc.
12/28/89	M.C.	FIELD B10-2 FEATURE MAP
		DESIGNED BY:
		DRAWN BY: JG
		DATE: 10/25/88

Figure 4

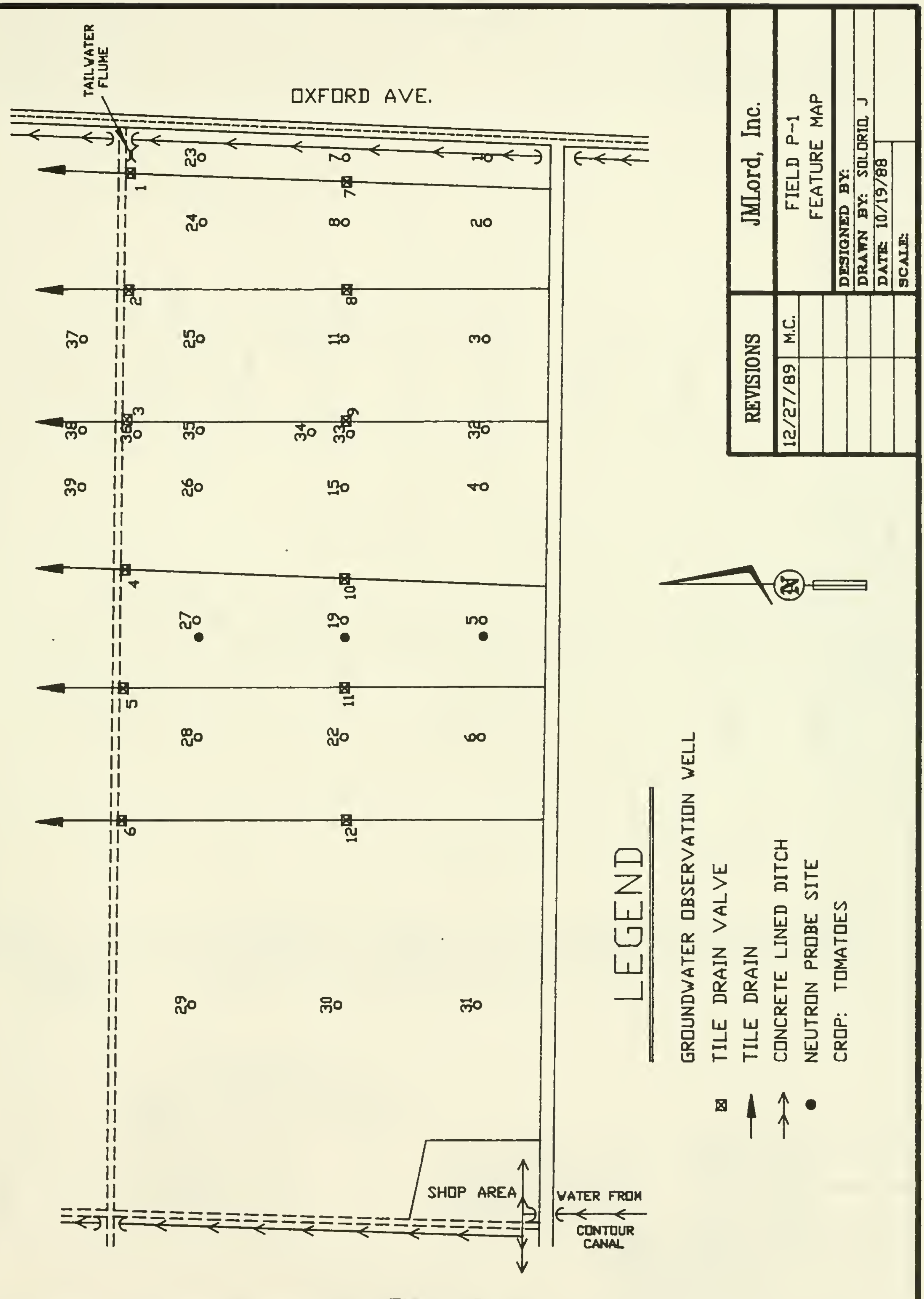
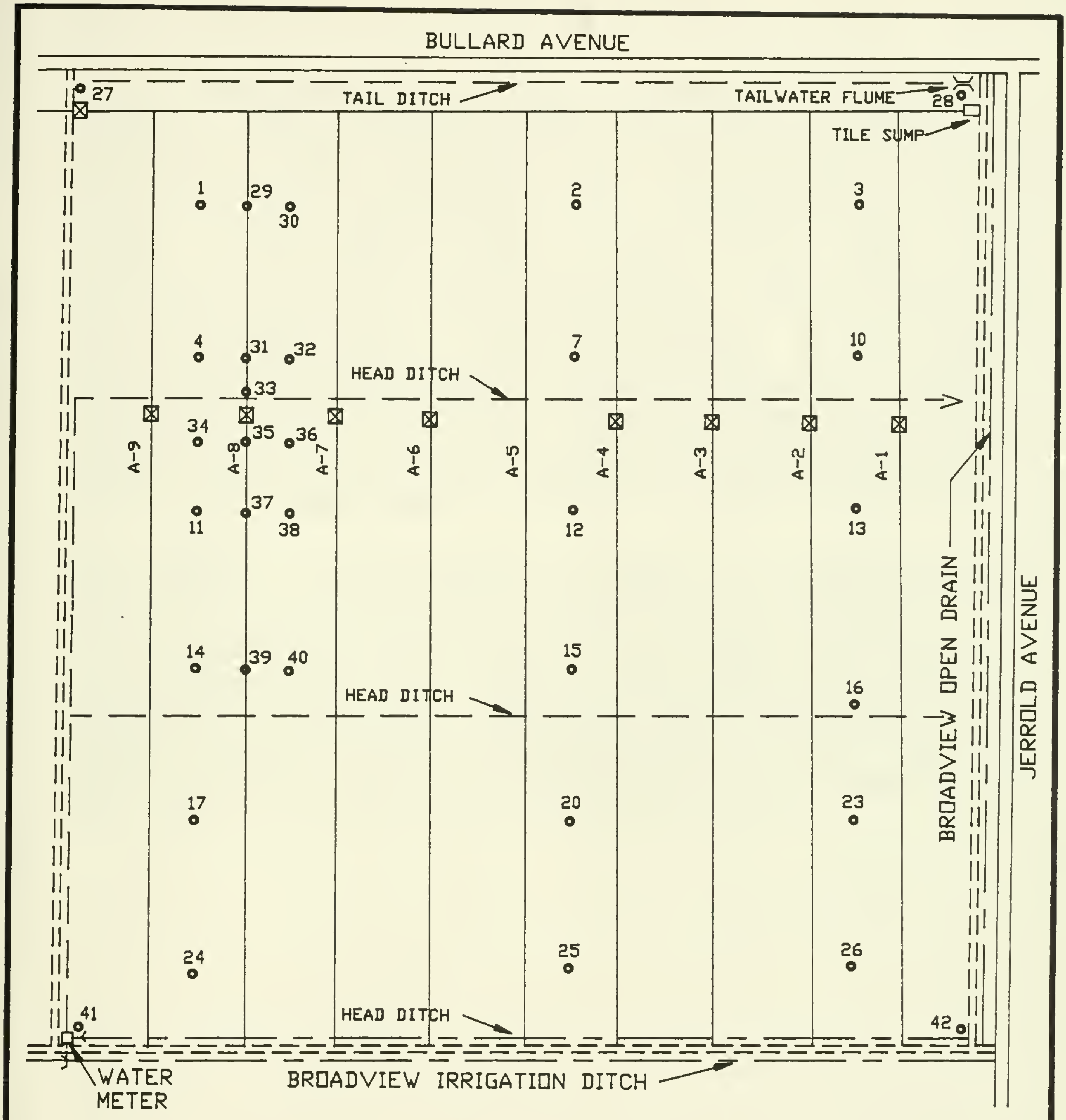

TAILWATER FLUME
OXFORD AVE.
SHOP AREA
WATER FROM CONTOUR CANAL
N
LEGEND
⊠ GROUNDWATER OBSERVATION WELL
TILE DRAIN VALVE
TILE DRAIN
CONCRETE LINED DITCH
● NEUTRON PROBE SITE
CROP: TOMATOES
JMLord, Inc.
FIELD P-1
FEATURE MAP
DESIGNED BY:
DRAWN BY: SOLORIO, J
DATE: 10/19/88
SCALE:
REVISIONS
12/27/89 M.C.

Figure 5



LEGEND

- ● GROUND WATER OBSERVATION WELL
- ☒ TILE DRAIN VALVE
- — TILE DRAIN

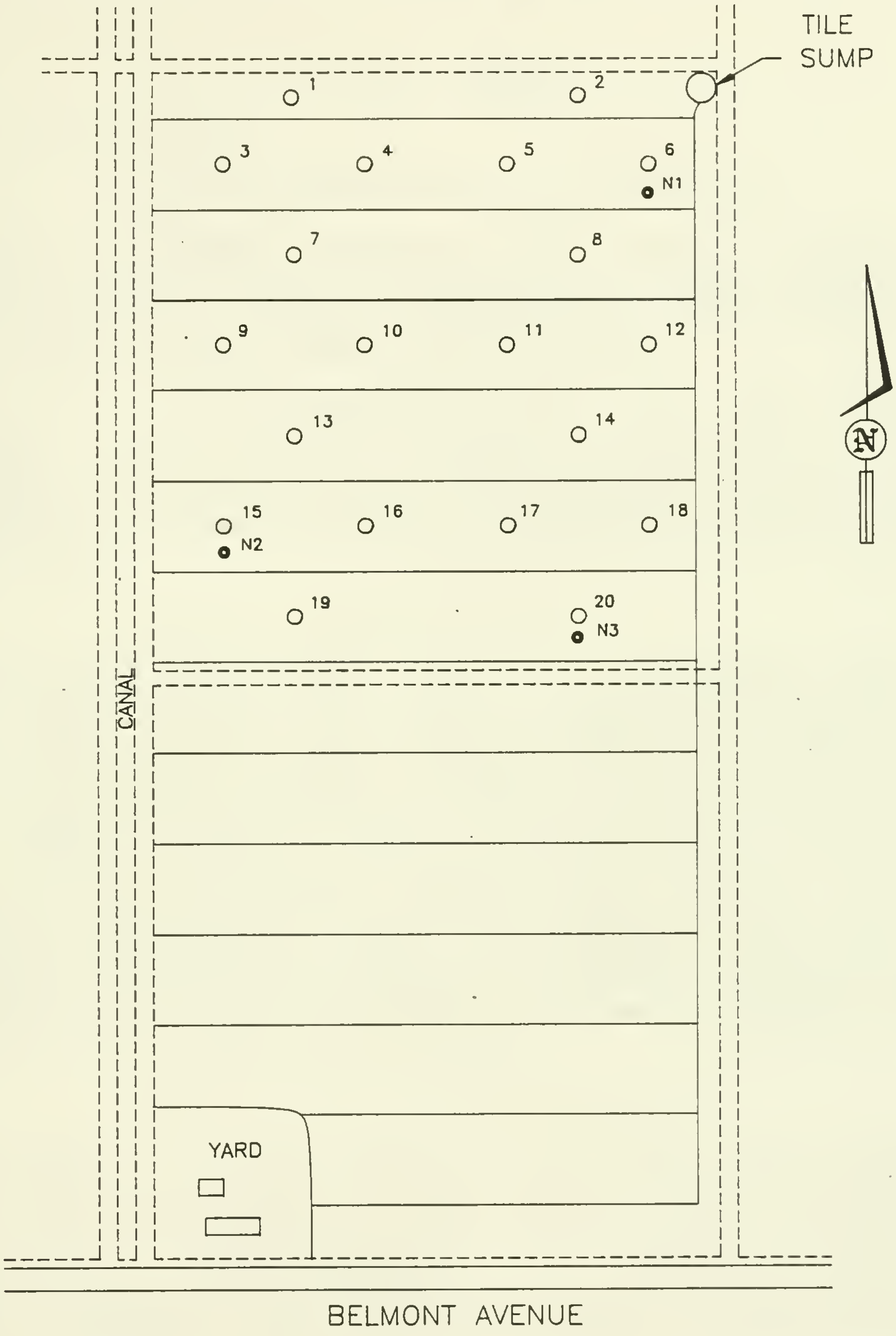
CROP: TOMATOES

Figure 6

REVISIONS		JMLord, Inc.
08/28/89	M.C.	FIELD B10-2 FEATURE MAP
12/28/89	M.C.	
		DESIGNED BY:
		DRAWN BY: JG
		DATE: 10/25/88
		SCALE:

Valves were removed from Field P-2. An additional study field was selected in Westlands Water District, Field W-3. It is shown in Figure 7. All three fields, B10-2, P-1 and W-3, were intensely monitored throughout the season. The drainage systems on Fields B10-2 and P-1 were actively controlled. The DOS-IR Valves' weirs on P-1 were set at approximately 2.5 - 3.0 feet below the ground surface. This effectively shut off the tile flow early in the season. This was done in an effort to keep the water table as high as possible in order to maximize crop use. Previous experience with this field indicated that unless maximum control was exercised the water table would be lower than desired. As the distance between the bottom of the root zone and the water table increases, the amount of water available from crop use decreases. The valves were going to be lowered (opened) later in the season as the water table rose. However, this was not necessary as the water table remained at the desired level or lower throughout the season. Opening the valves would have reduced water table contribution to the crop water requirement.

On Field B10-2, the DOS-IR Valves' weirs were set at 3.4 feet below the surface at the beginning of the season. In responding to the rising water table, the DOS-IR Valves' weirs in A-1 and A-2 were set to 5.7 feet on June 27. Valves 3 to 9 (except 5) were set to 4.4 feet below the ground surface. These changes were required to ensure adequate root zone extension and aeration. Due to Grower resistance and submerged tile lines the DOS-IR Valves could not be installed on Field W-3. The drainage system of W-3 was not actively managed but control over a portion of the field was effected early in season by not running the field's drainage sump pump. More will be said about these fields later.



LEGEND

○ OBSERVATION WELLS
● NEUTRON PROBE
—— DRAIN LINES
- - - - DIRT ROADS
CROP: COTTON

Figure 7

REVISIONS:	
5/31/89	JS
0/17/90	MC

JMLord, Inc.

SJVDP FIELD W3

DRAWN BY: M.C.
DATE: 02/13/89
SCALE:

II. METHODS

A. Phase II methods

1. Irrigation deliveries and tailwater flows

Irrigation deliveries to each of the fields were measured using propeller flow meters with instantaneous and totalizing indicators. Tailwater runoff leaving the field was measured by Parshall flumes with continuous water level recorders. Water quality tests of the irrigation water were made by the districts.

The first three irrigations on each field were evaluated to estimate the distribution uniformity of the infiltrated water. Evaluation methods used were similar to those used in the Westside Resource Conservation District and Westlands Water District Water Conservation and Drainage Reduction Program but with considerably more detail.

2. Tile drain flows and quality

Depending on the physical layout of the tile system outlet, three different measurement techniques were used depending on the outlet conditions. For gravity discharge a graduated five gallon bucket and a stop watch were used. For non-gravity discharge either the DOS-IR Valves were used as access ports to measure actual tile line and collector line flows with an electro-magnetic velocity meter or a propeller meter was mounted on the discharge of the sump pump.

Monthly water samples were taken from each measuring point. The electrical conductivity (EC) analysis was done with a Wheatstone Bridge Meter with automatic temperature adjustment. The colorimetric method was used to analyze for boron. Selenium analysis was completed using the hydride generation/atomic absorption spectrophotometry method.

3. Shallow groundwater levels and quality

The shallow groundwater levels in each field were monitored by installing 10 foot lengths of 1.5 inch diameter, slotted PVC pipe in 9.5 foot auger holes. Each hole was back filled with sand. The end of the pipe was capped to prevent soil intrusion. The locations of the observation wells were selected to provide as much information about the spatial variability of the groundwater in the field as possible, while limiting the number of sites to around 25. Each field was surveyed to map the location and elevation of each observation well precisely.

The depth to groundwater was read on a regular basis, normally weekly. Water samples were drawn once in the winter and once in the summer for EC and boron analysis.

4. Soil physical and chemical properties

As each observation well hole was augered, it was logged for soil texture, structure, apparent permeability, color, and moisture content. Individual soil samples were taken from each foot in the top five feet of the soil profile. Each sample was analyzed for pH, EC, boron, sodium, calcium, magnesium, chloride and nitrate.

Hydraulic Conductivity measurements were taken at four sites in each field. The standard Bureau of Reclamation bailout method was used. These tests were run in four inch auger holes shortly after the pre-irrigation. Additionally, pressure plate analysis was conducted on soil samples taken from these holes.

5. Evapotranspiration and soil moisture

Evapotranspiration rates were calculated using SWAP/ET (JMLord, Inc's. irrigation scheduling model) with weather input from the California Irrigation Management Information Service (CIMIS) weather station #7 (Firebaugh). SWAP/ET uses a modified Penman equation to calculate evaporation potential.

Soil moisture measurements were taken at three different sites with a neutron probe. Readings were taken from zero to five feet in one foot increments.

6. DRAINMOD

DRAINMOD was designed to model the hydrology of humid zone drainage conditions and has not been extensively tested under irrigated arid conditions. Therefore, during the 1988 crop season the field data necessary to allow the testing of DRAINMOD as a management tool was gathered. The goal was to determine if DRAINMOD could track water table fluctuations under Westside conditions in order to use it as a tool in determining future irrigation management and controlled drainage techniques.

B: Phase II Data Analysis

The data collected in Phase II, the 1988 cropping season, was used to identify the following items:

1. Determined water and constituent load destinations. This included constituents entering the field through irrigation water and those leaving through tailwater runoff and tile flows.

2. Determined amounts of water movement from the saturated zone into the crop root zone. This is defined as upflux. The salt movement with the upflux was also estimated.

3. Predicted water table depths and tile flows were compared with field data and DRAINMOD version 3.0 simulations.

C. Additional methods developed in Phase III

1. DOS-IR Valve water table control

One DOS-IR Valve/tile line in Field B10-2 and another one in P-1 was chosen to be much more intensely monitored in Phase III than in Phase II. This was done to study the water table profile upstream and downstream of the DOS-IR Valve. In Field B10-2 an additional 12 observation wells were added along tile line 8 and around DOS-IR Valve A-8. This brought the total number of observation wells installed in B10-2 during the 1989 cropping season to 34. Figure 6 shows their layout. In Field P-1 eight additional observation wells were added along tile line 3 and DOS-IR Valve 3, which brought the total number of observation wells installed in P-1 during the 1989 cropping season to 29. Figure 5 shows their layout.

2. DRAINMOD 4.0

DRAINMOD 4.0 was used to model each field's drainage system. Version 4.0 is considerably more user friendly than version 3.0. A new file manager has been added that makes it easier to maintain and modify required files. Provisions for vertical flow, lateral flow and down slope flow have been added. Provisions have also been made to enable part year modeling. In version 3.0 the minimum modeling time unit was one year.

3. Salinity model

A soil salinity model developed by Dr. R.J. Hanks of Utah State University was investigated to determine its applicability for salt flow modeling under Westside conditions. Some of the model's assumed boundary conditions greatly limit its usefulness for the study field conditions. One of the biggest limitations is that the model assumes a static water table over the run-time period. This does not conform to Westside conditions. The water table depth and quality vary significantly both spatially and temporally and the model was not designed for these conditions. There is currently work being done at USU to address some of these areas. It should be noted that runs were made but the results obviously did not reflect field salinity conditions. With time the model could be modified, but it was beyond the scope of this study to do this. It should be noted that there are other salinity models available and they would merit investigation in future studies.

III. 1989 ANALYSIS

A. Irrigations

1. Field B10-2

Table 1 summarizes the irrigation data collected on Field B10-2 during the 1989 cropping season. A total of 29.6 inches of water was applied of which, 19 inches infiltrated, 10.6 inches were lost as tailwater and 1.9 inches went to deep percolation. A volume balance at each neutron probe site was used to calculate deep percolation. Irrigation amounts, evapotranspiration, and change in soil moisture were the primary parameters for the volume balance. The reported deep percolation value is an average of three sites. Since the tailwater is lost to the farm, the irrigation efficiency can be defined as (beneficial use)/(gross applied). The seasonal irrigation efficiency was 57%. If the tailwater could have been reused the irrigation efficiency would have been 90%. This is common where soil sealing reduces infiltration rates, which can cause large runoff losses and some under irrigation. The seasonal water destination graph is shown in Figure 8. It should be noted that upflux provided approximately 18% or 3.4 inches of the crop water requirement. The portion of the graph labeled "under irrigation" indicates the area of the field that would have been under irrigated if there had been no water table contribution. It can be seen that the sum of the irrigations and the upflux provide adequate irrigation for the crop ET over the full length of the field.

Table 1 - Field B10-2 Irrigation Summary

Date	System	Gross Applied (in.)	Run-Off (in.)	Average Infiltration (in.)	DU* %
5/3-5/22	HM	5.6	.2	5.4	49
6/11-6/18	F	4.9	.7	4.2	75
6/23-6/18	F	3.5	1.4	2.1	
7/5-7/10	F	2.1	1.3	0.8	
7/11-7/16	F	2.2	1.7	0.5	
7/17-7/22	F	2.1	1.5	0.6	
7/23-7/28	F	2.2	1.1	1.1	

Table 1 (cont.) - Field B10-2 Irrigation Summary

Date	System	Gross Applied (in.)	Run-Off (in.)	Average Infiltration (in.)	DU* %
7/30-8/4	F	2.5	.5	2.0	
8/7-8/12	F	2.1	.6	1.5	95
8/13-8/19	F	2.4	1.6	0.8	
Totals for year:		29.6	10.6	19.0	

*DU as evaluated

HM = Handmove sprinklers

F = Furrow irrigated

Germination irrigations employed sprinklers with 7/64" nozzles. Three inch by one-half mile laterals were used. The distribution uniformity (DU) as evaluated was 49%. The DU was very poor because of a 40 to 47 psi pressure loss along the laterals. Typically, when using 3" laterals on a quarter section, growers will run the mainline slightly uphill from the field center line instead of along the field edge. This shortens the lateral length and reduces the pressure loss. The grower chose not to do this.

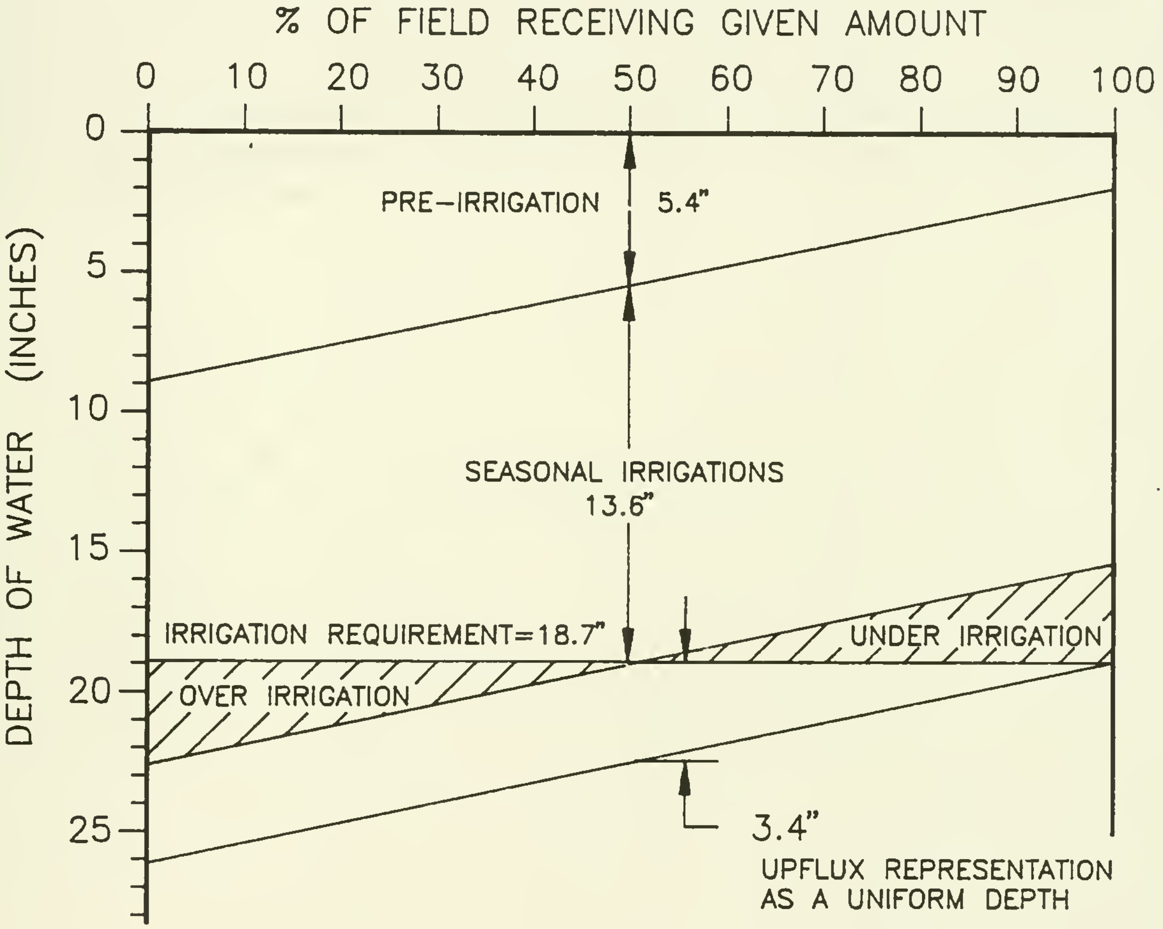
The remainder of the season the field was furrow irrigated with 1/6 mile runs (880 ft.) and siphon tubes. Each third of the field had its own head ditch and tailwater ditch. The water was metered onto the field by Broadview Water District. All tailwater was channeled through a nine inch Parshall Flume with a continuous depth recorder and discharged into the Broadview open drain. The first seasonal irrigation and a late seasonal furrow irrigation were evaluated, and DU values of 75% and 95%, respectively, were obtained.

2. Field P-1

Table 2 summarizes the irrigation data collected on Field P-1. A total of 35.5 inches was applied. Approximately 21.7 inches infiltrated, 9.8 inches left the field as tailwater run off and 4.0 inches were spilled out the end of the head ditch. Of the 21.7 inches infiltrated, 3.8 inches went to deep percolation. Since the tailwater runoff and the head ditch spillage were captured and reused on another field, the irrigation efficiency can be defined as beneficial use/average amount infiltrated. Neglecting upflux of 2.6 inches and including an estimated 5% conveyance/recapture loss, the seasonal irrigation efficiency was 80%. If the tailwater

WATER DESTINATION GRAPH

Field B10-2,1989



TOTAL IRRIGATIONS=5.4"+13.6"=19"
PORTION OF ET SATISFIED BY
UPFLUX (18%)=3.4"
SEASONAL DU=85%

JMLord, Inc.	
Field B10-2	
DRAWN BY: MC	
DATE: 12/26/89	
SCALE: NONE	

Figure 8

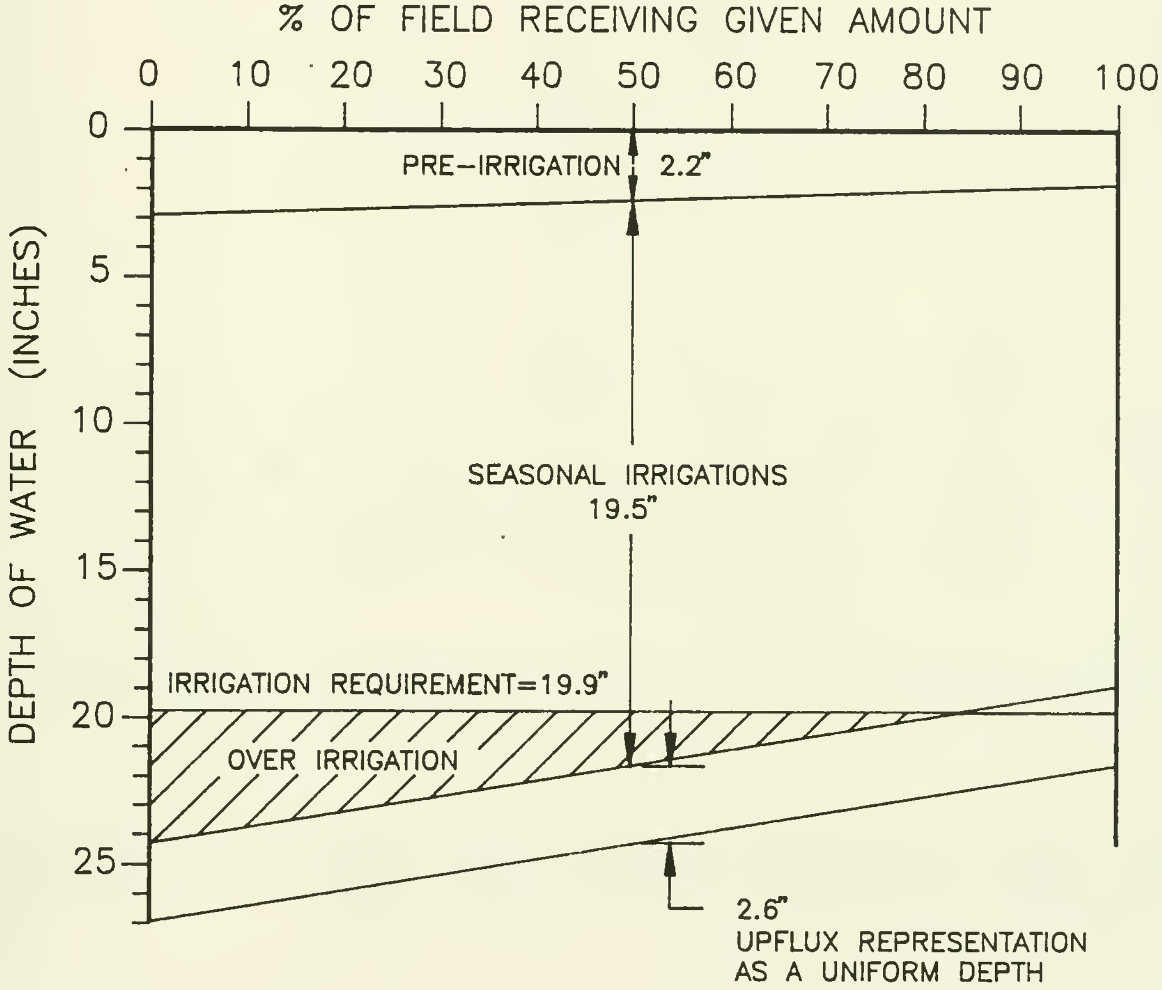
and head ditch spillage were lost, the seasonal irrigation efficiency would have been 54%. The seasonal water destination graph is shown in Figure 9.

Germination irrigations employed hand move sprinklers with 7/64 inch nozzles. Lateral lines were 3 inches in diameter and a quarter mile long. Distribution uniformity as determined by field evaluation was 89%.

The remainder of the season the field was furrow irrigated with quarter mile furrows. The water was measured onto and off of the field with 12 and 9 inch Parshall Flumes, respectively. Each flume was setup with a continuous acting stage recorder. The first seasonal and mid seasonal irrigations were evaluated using a furrow evaluation program and field monitoring of furrow stream flows and other field parameters. The DU on both of these irrigations was in excess of 80%.

WATER DESTINATION GRAPH

Field P-1, 1989



TOTAL IRRIGATIONS=2.2"+19.5"=21.7"
PORTION OF ET SATISFIED BY
UPFLUX (13%)=2.6"
SEASONAL DU=90%

JMLord, Inc.	
Field P-1	
DRAWN BY: MC	
DATE: 12/26/89	
SCALE: NONE	

Figure 9

Table 2 - Field P-1 Irrigation Summary

Date	System	Gross Applied (in.)	Run-Off (in.)	Spill (in.)	Average Infiltration (in.)	DU* %
3/17	HM	2.4	--	0.2	2.2	89
3/24	HM	1.6	--	0.2	1.4	
4/5	HM	1.6	--	0.2	1.4	
5/1	F	3.9	.5	1.3	2.1	90
5/12	F	3.5	.4	1.6	1.5	
5/24	F	4.7	.5	1.3	2.9	
6/4	F	4.4	.5	1.3	2.6	
6/10	F	7.5	1.2	2.5	3.8	
6/22	F	4.0	.7	.9	2.4	
7/1	F	1.9	.2	.3	1.4	
	Totals	35.5	4.0	9.8	21.7	

*DU as evaluated

HM = Hand move sprinklers F = Furrow irrigated

3. Field W-3

Table 3 summarizes the irrigation data collected on Field W-3. As indicated 31.6 inches were applied, of which 29.8 inches infiltrated. There were approximately 1.8 inches that ran off the field.

Table 3 - Field W-3 Irrigation Summary

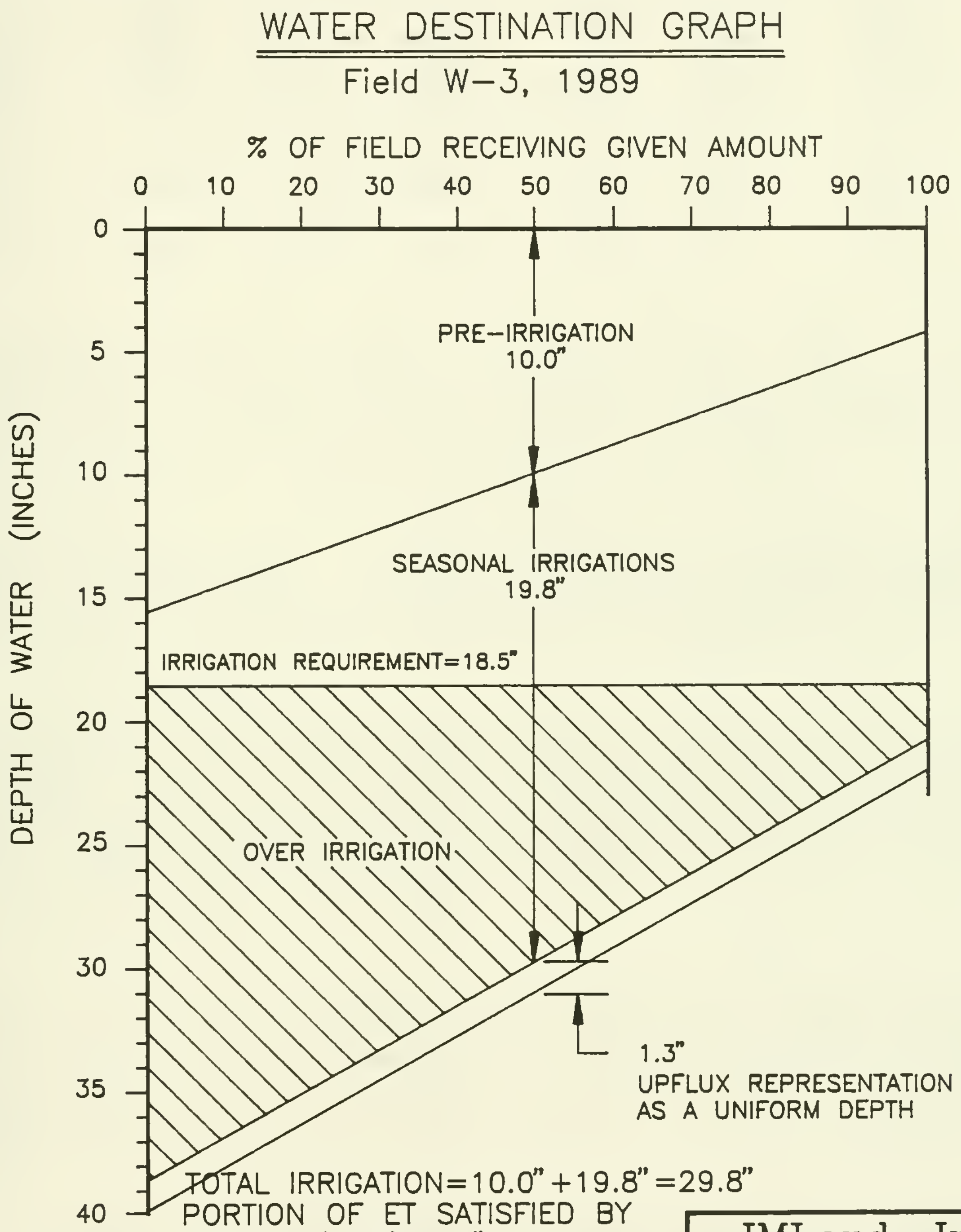
Date	System	Gross Applied (in.)	Losses (in.)	Average Infiltration (in.)	DU* %
1/18	HM	10.6	0.6	10.0	56
6/23	F	5	0.3	4.7	85
7/10	F	5.6	0.3	5.3	
7/26	F	6.6	0.4	6.2	
8/17	F	3.8	0.2	3.6	
Totals		31.6	1.8	29.8	

The pre-irrigation was completed using hand move sprinklers with half mile lateral lengths and low pressure nozzles. The DU as evaluated was 56%. The remainder of the season the field was furrow irrigated with 1/6 mile runs. The first furrow irrigation was evaluated and the DU was 85%. The water was metered onto the field and there was little runoff. The seasonal water destination graph is shown in Figure 10.

B. Tile drain flows and constituent loads

1. Field B10-2

Table 4 shows the tile drain data summary for Fields B10-2 and B10-1. The total quantity of tile water pumped into the Broadview open drain from these two fields was 88.07 ac-ft. An estimated 58.75 ac-ft came from B10-1 and 29.32 ac-ft came from B10-2. The average EC of the tile effluent was 7.68 dS/m. The average boron and selenium concentrations were 6.37 ppm and 0.076 ppm, respectively. For B10-2 during the 1989 season this translates into the followingconstituent loads: salt = 214 tons, boron = 507 lbs. and selenium = 6.1 lbs.



TOTAL IRRIGATION=10.0"+19.8"=29.8"
PORTION OF ET SATISFIED BY
UPFLUX (12%)=1.3"
ESTIMATED SEASONAL DU=80%

JMLord, Inc.
Field W-3
DRAWN BY: MC
DATE: 12/26/89
SCALE: NONE

Figure 10

Table 4 - Field B10-2 Tile Drain Data Summary

Field No.	Total Flow ac-ft	Avg. EC dS/m	Avg. Boron ppm	Avg. Se ppm	Salt Load tons	Boron Load lbs	Se Load lbs
B10-1	58.75	7.68	6.37	.054	429	1016	8.6
B10-2	29.32	7.68	6.37	.054	214	507	4.3
Totals	88.07	7.68	6.37	.054	643	1523	12.9

Average laboratory results for Broadview Water District's irrigation water were EC = 0.85 dS/m and boron = 0.72 ppm. Approximately 18% of water delivered in Broadview Water District consists of recycled tailwater and drain water. The constituent load infiltrated with the 19 inches of irrigation water is as follows: salts = 186 tons and boron = 452 lbs.

These data indicate that approximately 15% and 12% more salts and boron, respectively, left the soil profile than was applied with the irrigation water. It must be noted that these figures do not represent salts added from amendments and upslope sources.

2. Field P-1

As was previously mentioned the tile system on Field P-1 was managed such that there was no tile flow over the course of the season. Again, this was done in order to maintain the shallowest water table possible in order to maximize crop water use. Under this condition there was no measurable tile flow and hence no measurable constituent loads.

3. Field W-3

Due to Grower resistance and high water table conditions the DOS-IR Valves could not be installed on Field W-3. This necessitated estimation of tile flows based on deep percolation losses. The constituent loads are based on estimated flows and laboratory analysis of tile drain water quality. Table 5 summarizes these data.

Table 5 - Field W-3 Estimated Tile Drain Data Summary

Field No.	Total Flow ac-ft	Avg. EC dS/m	Avg. Boron ppm	Avg. Se ppm	Salt Load tons	Boron Load lbs	Se Load lbs
W-3	68	7.30	4.45	.085	472	823	16

Based on laboratory analysis of the irrigation water, a mixture of tile drain water and tailwater runoff, the average EC was 2.0 dS/m and boron levels were found to be 0.84 ppm. The constituent load infiltrated with the 29.8 inches of irrigation water is as follows: salts 736 tons and boron 884 lbs. These data show that approximately 60% more salts infiltrated with the irrigation water than left the field in the drain water. It must be noted that these figures do not represent salts added from amendments and upslope sources.

Neglecting all other sources of salts the addition of 264 tons of salt to the five foot soil profile in this field would raise the average soil ECe by 0.5 to 0.75 dS/m.

C. Shallow groundwater monitoring

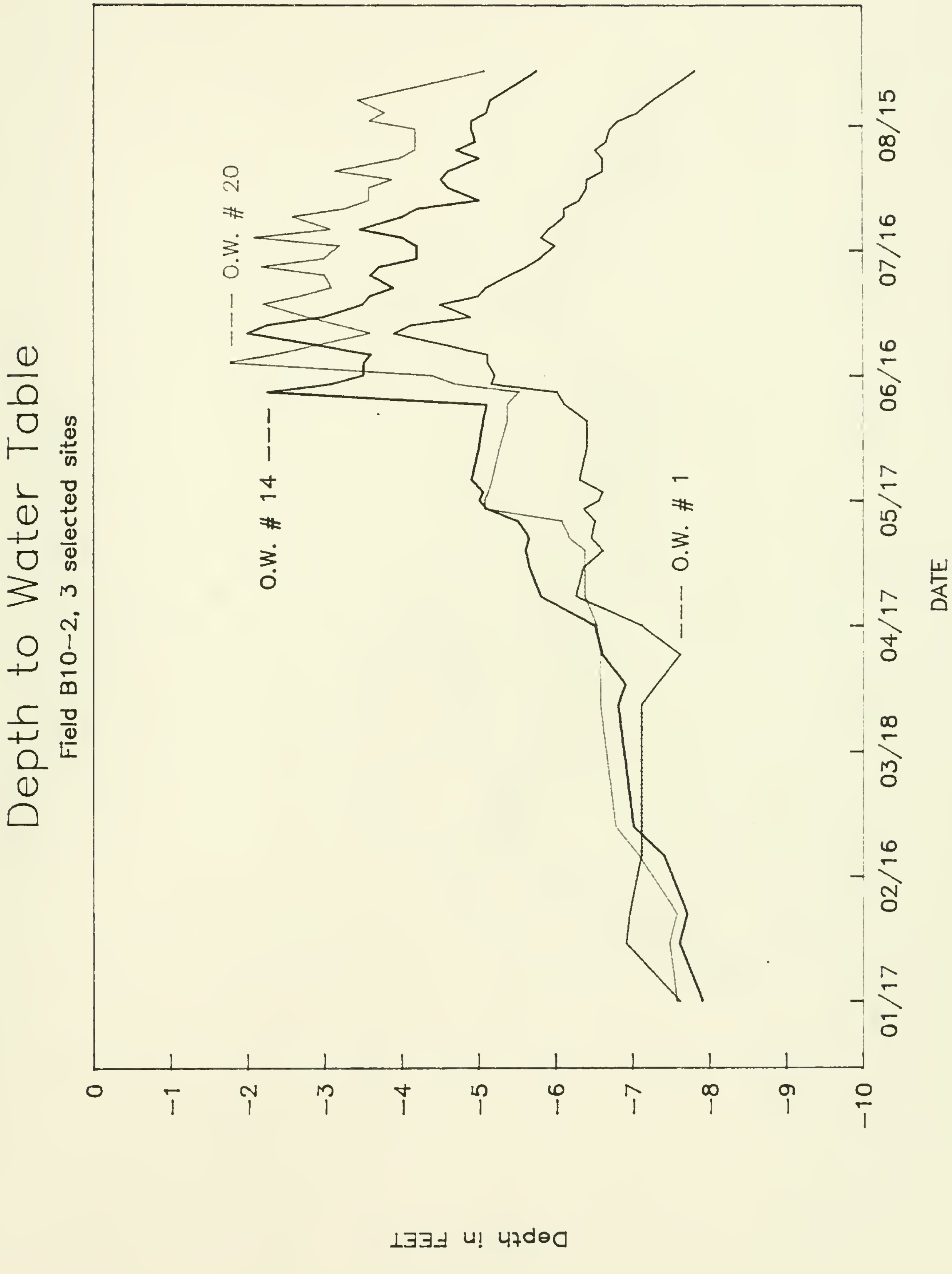
In all three fields a grid of observation wells was installed to monitor the shallow water table over the course of the season. Figures 5, 6, and 7 show the layout. Field B10-2 had a total of 34 observations wells, P-1 had 29 wells and W-3 had 20 wells. There was considerable spatial variability of the water table in all fields. Figures 11, 12 and 13 show water table depth versus time for three selected wells in each field. The three wells chosen were those that showed water table depths that were relatively deep, relatively shallow and an approximate average. The water table information was also used to develop depth to water table contour maps. These maps were generated weekly and were an aid in scheduling irrigations. Figures 14, 15 and 16 show examples of these water table contour maps for each field. These particular examples show the water table at its shallowest.

Shallow groundwater samples were taken from the observation wells for laboratory analysis twice during the growing season. Figures 17, 18, and 19 show that there is considerable variability with location in the EC levels.

D. Soils

The 10 foot soil profiles of all three fields showed diverse stratification. The stratification in each field varied from a fairly coarse sand to a heavy clay. However, the predominant soil type was a silty clay loam, which is quite typical of Westside soils. Average soil salinity results for each field are listed in Tables 6, 7 and 8. The salinity levels varied considerably by location and by depth. It should be noted that tomatoes may start showing a yield reduction if the ECe is above 2.5 dS/m. Field B10-2 (tomatoes) shows average ECe levels higher than this threshold level throughout the profile. Field P-1 (tomatoes) shows

Figure 11



Depth to Water Table

Field B10-2, 3 selected sites

Figure 12

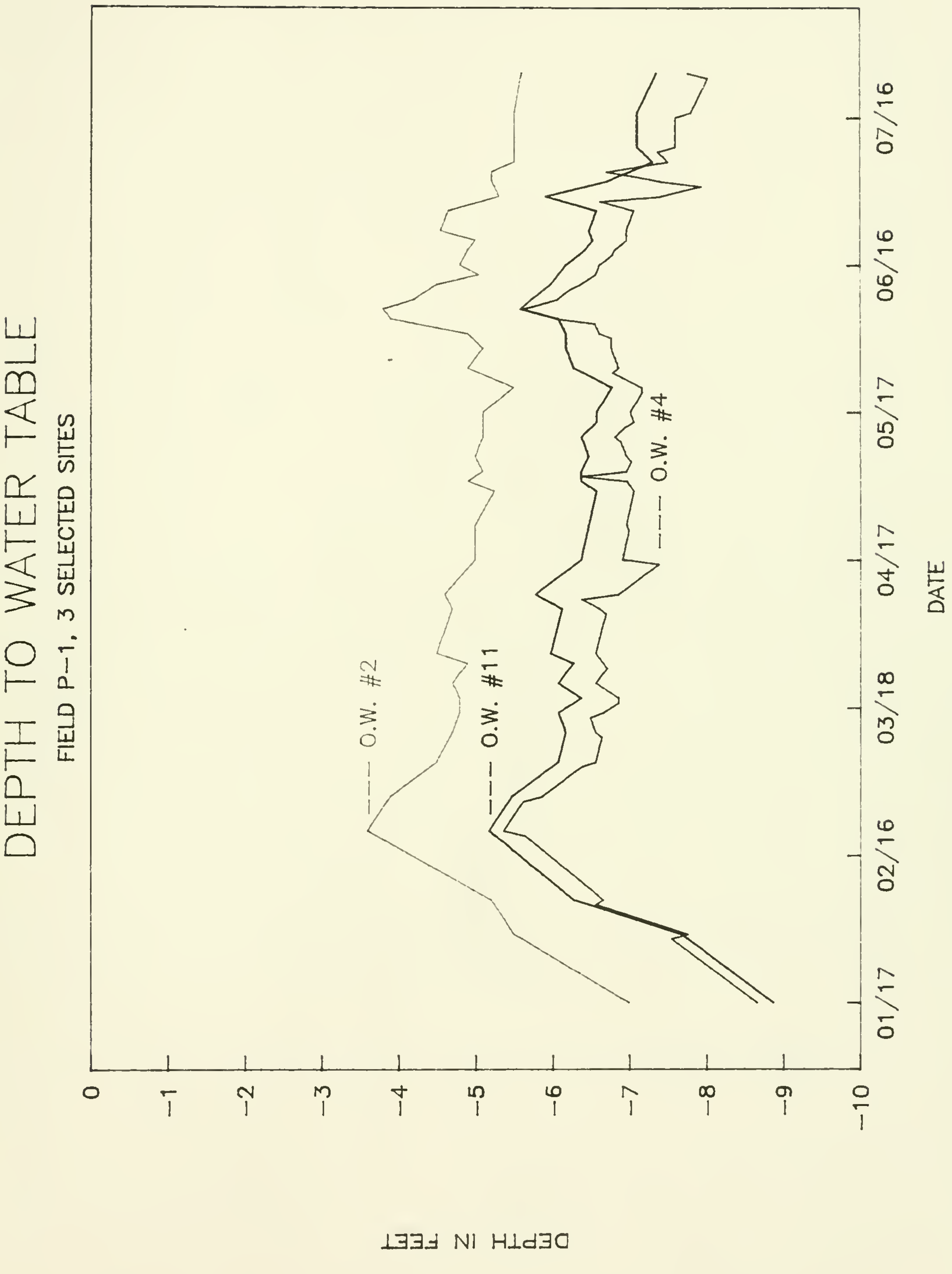
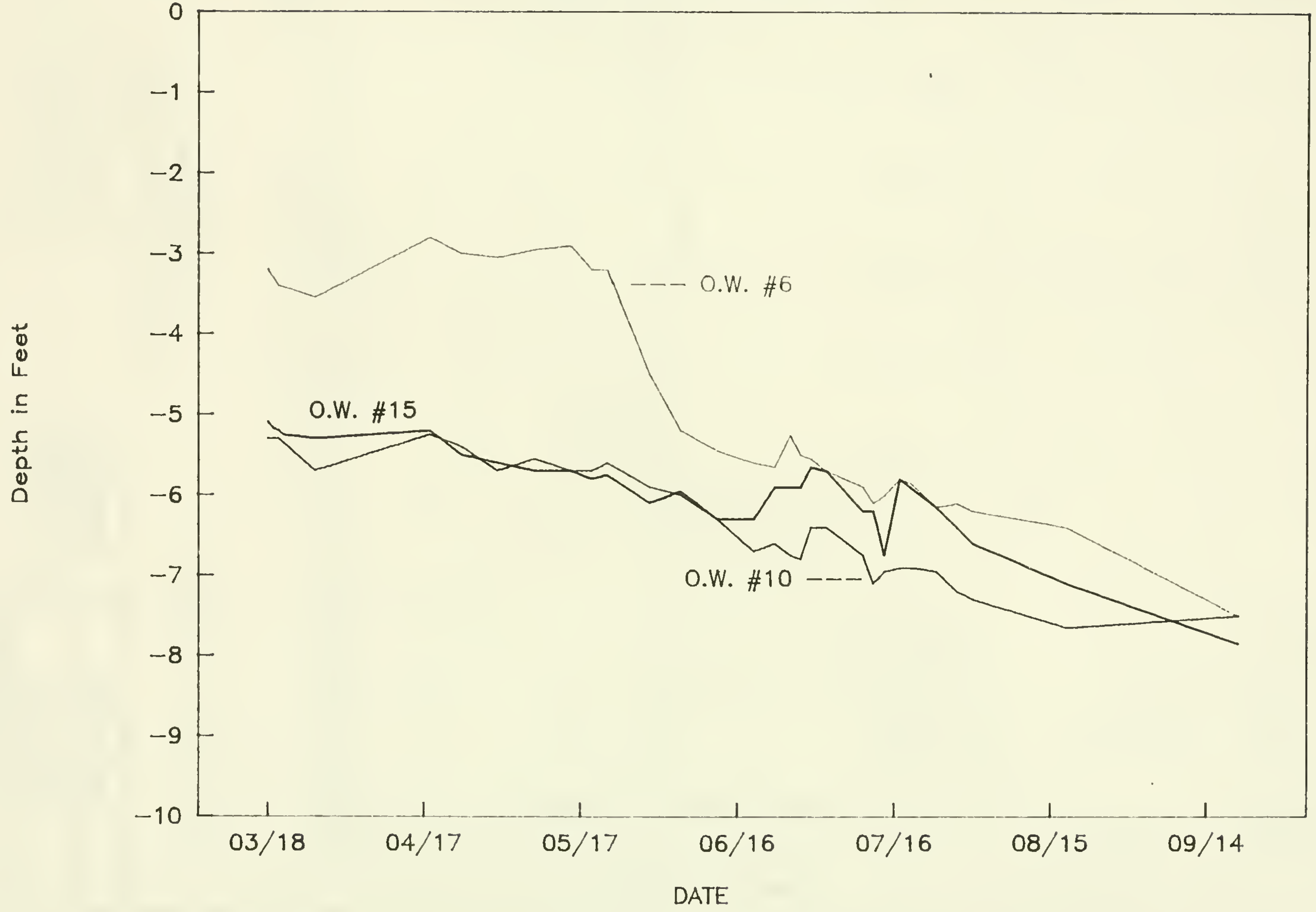
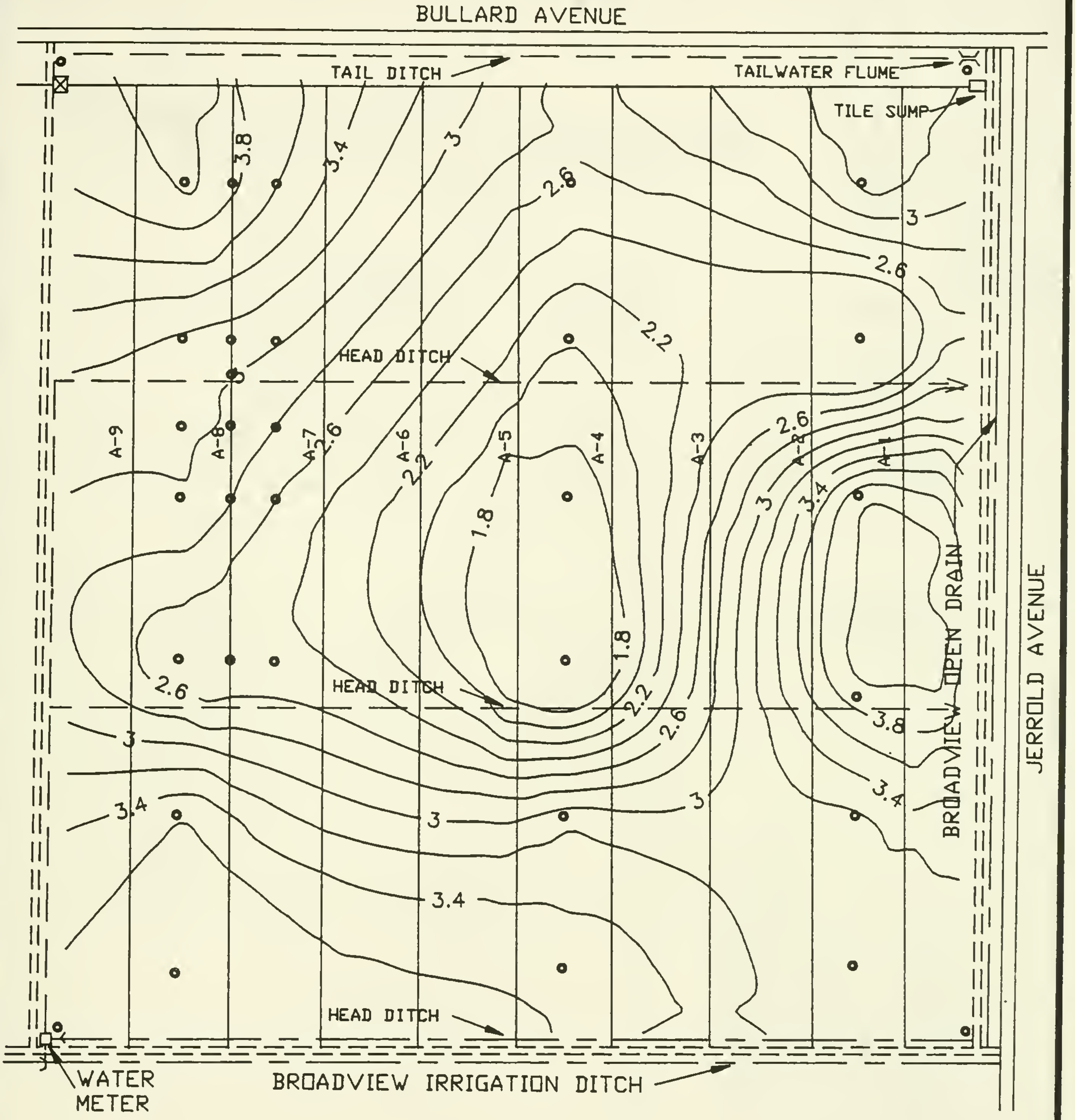

DEPTH TO WATER TABLE
FIELD P–1, 3 SELECTED SITES
O.W. #2
O.W. #11
O.W. #4
0
–1
–2
–3
–4
–5
–6
–7
–8
–9
–10
DEPTH IN FEET
01/17
02/16
03/18
04/17
05/17
06/16
07/16
DATE

Figure 13



Depth to Water Table

Field W-3, 3 Selected Sites



LEGEND

○ GROUND WATER OBSERVATION WELL

☒ TILE DRAIN VALVE

— TILE DRAIN

CROP: TOMATOES

DEPTH TO WATER TABLE
6/28/89

Figure 14

REVISIONS		JMLord, Inc.
08/28/89	M.C.	FIELD B10-2 FEATURE MAP
12/28/89	M.C.	
		DESIGNED BY:
		DRAWN BY: JG
		DATE: 10/25/88
		SCALE:

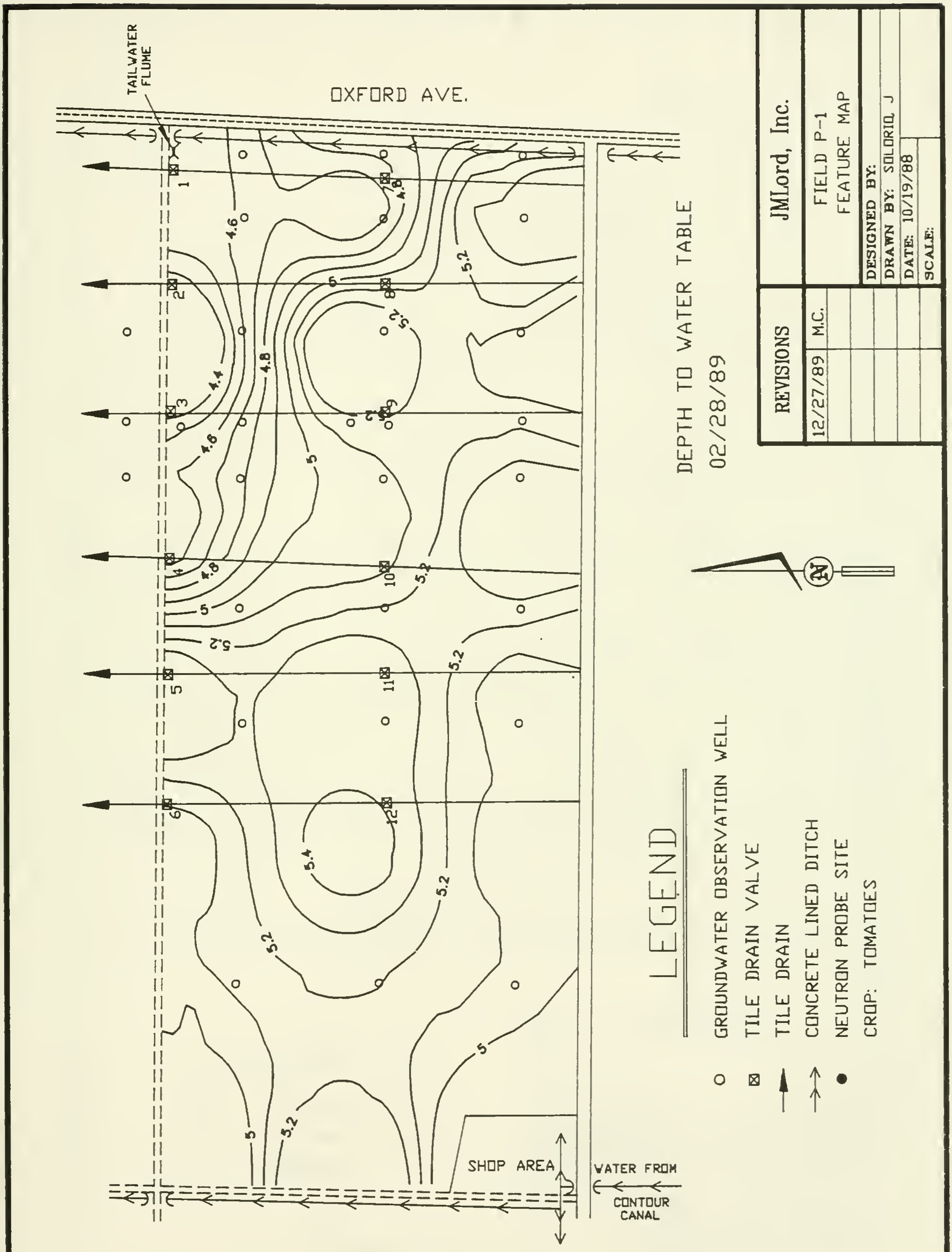
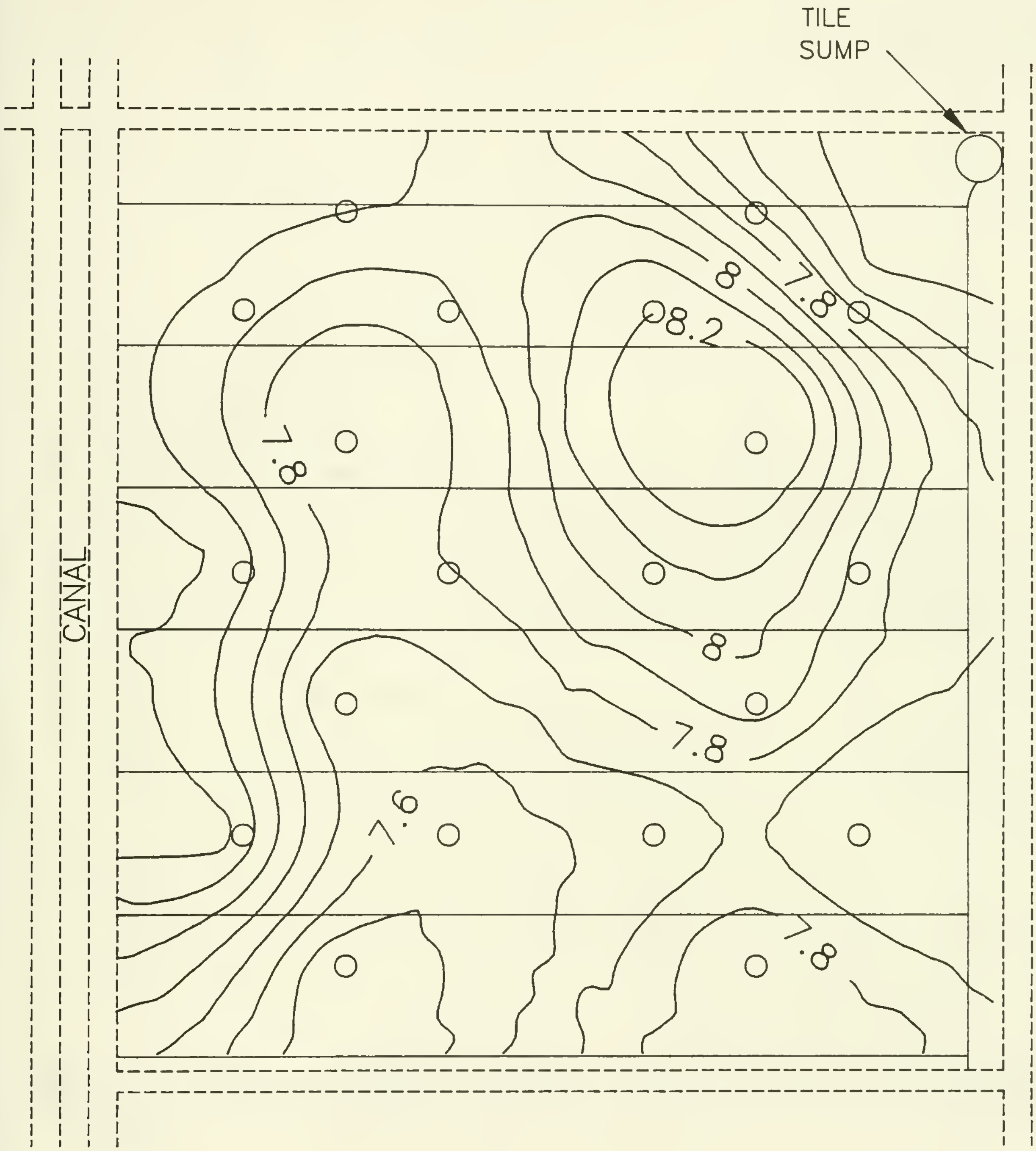

TAILWATER FLUME
OXFORD AVE.
DEPTH TO WATER TABLE
02/28/89
LEGEND
○ GROUNDWATER OBSERVATION WELL
☒ TILE DRAIN VALVE
TILE DRAIN
CONCRETE LINED DITCH
● NEUTRON PROBE SITE
CROP: TOMATOES
SHOP AREA
WATER FROM CONTOUR CANAL
N
4.4
4.6
4.8
5
5.2
5.4
1
2
3
4
5
6
7
8
9
10
11
12
JMLord, Inc.
FIELD P-1
FEATURE MAP
DESIGNED BY:
DRAWN BY: SOLORIO J
DATE: 10/19/88
SCALE:
REVISIONS
12/27/89 M.C.

Figure 15



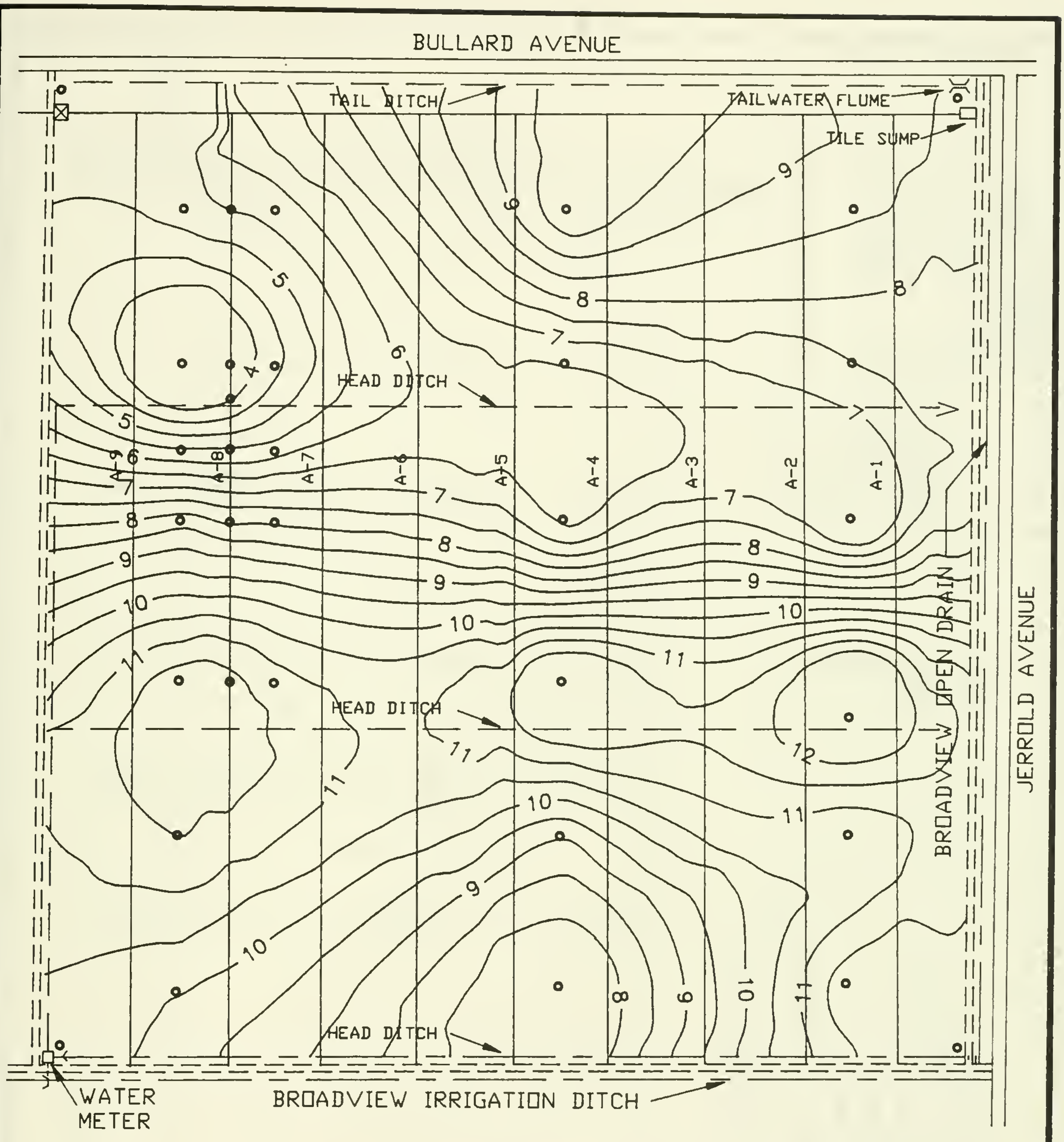
DEPTH TO WATER TABLE
09/20/89

LEGEND

- - - - - - DIRT ROADS
○ OBSERVATION WELLS
—— TILE DRAIN

Figure 16

REVISIONS:		JMLord, Inc.
5/31/89	JG	SJVDP FIELD W3
12/28/89		DRAWN BY: M.C.
		DATE: 02/13/89
		SCALE:



AVE. GROUNDWATER EC (dS/m)
04/03/89

LEGEND

○ GROUND WATER OBSERVATION WELL

☒ TILE DRAIN VALVE

— TILE DRAIN

CROP: TOMATOES

REVISIONS		JMLord, Inc.
08/28/89	M.C.	FIELD B10-2 FEATURE MAP
01/04/89	M.C.	
		DESIGNED BY:
		DRAWN BY: JG
		DATE: 10/25/88
		SCALE:

Figure 17

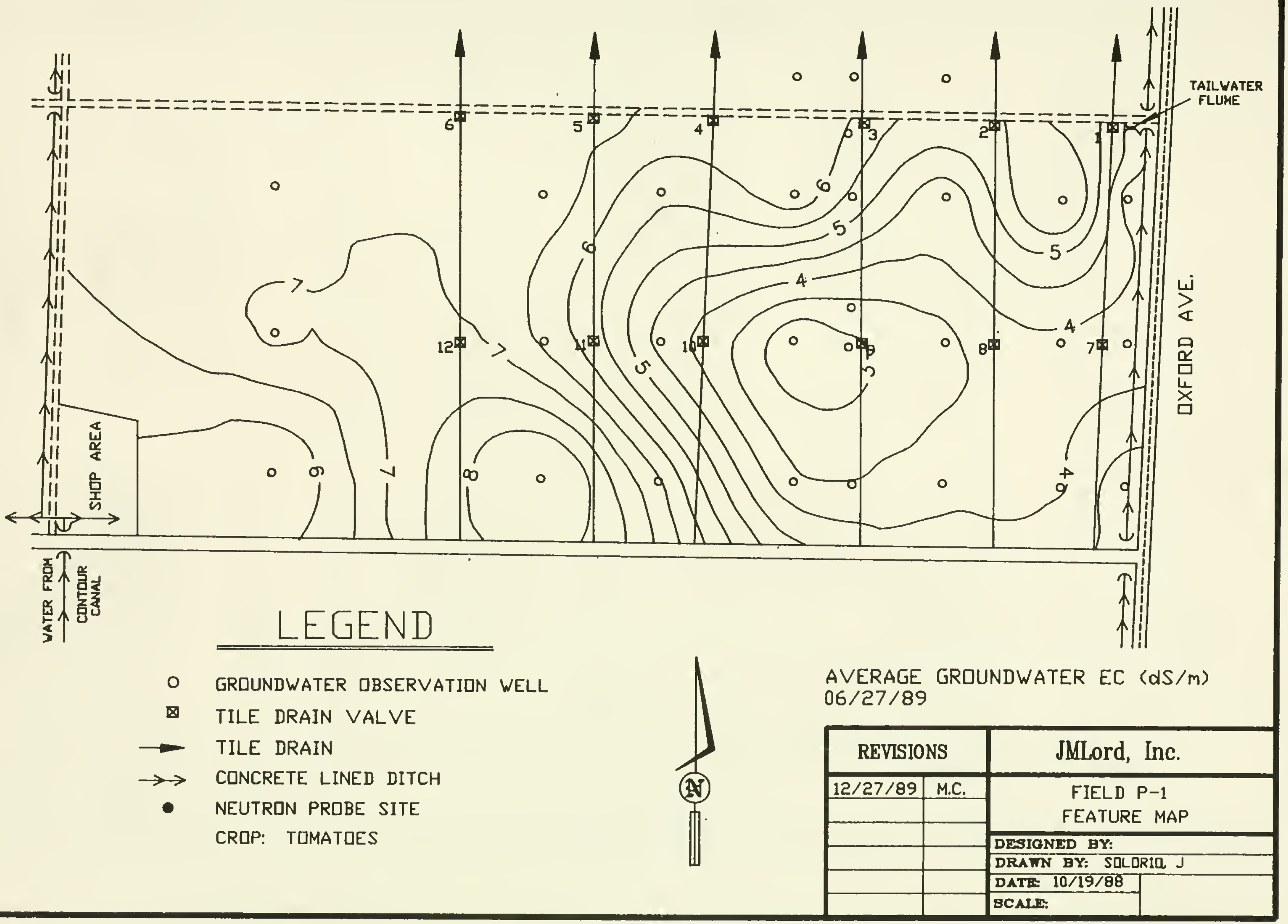
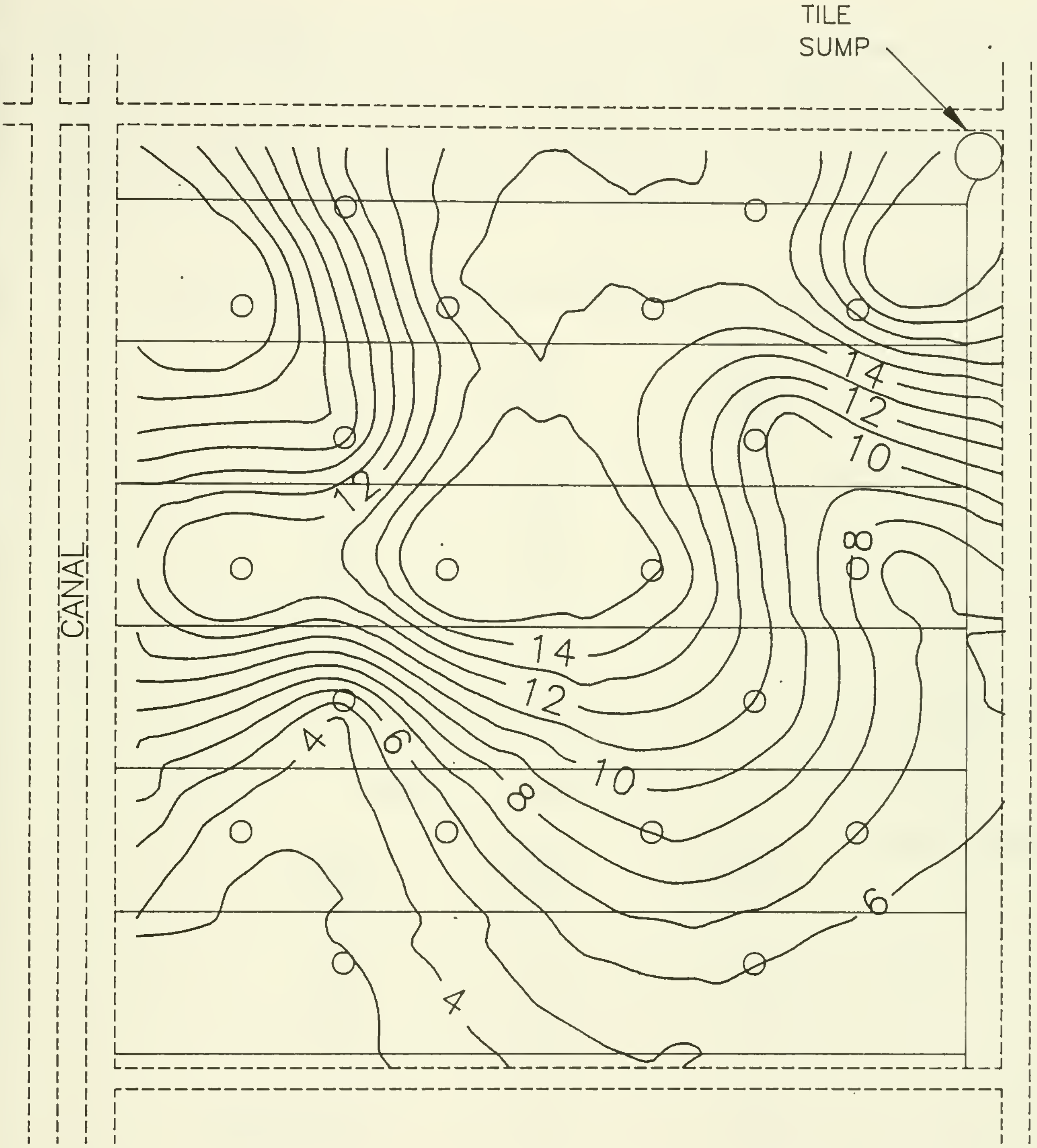

TAILWATER FLUME
OXFORD AVE.
SHOP AREA
WATER FROM CONTOUR CANAL
1
2
3
4
5
6
7
8
9
10
11
12
4
5
6
7
8
LEGEND
○ GROUNDWATER OBSERVATION WELL
⊠ TILE DRAIN VALVE
TILE DRAIN
CONCRETE LINED DITCH
● NEUTRON PROBE SITE
CROP: TOMATOES
N
AVERAGE GROUNDWATER EC (dS/m)
06/27/89
REVISIONS
12/27/89
M.C.
JMLord, Inc.
FIELD P-1
FEATURE MAP
DESIGNED BY:
DRAWN BY: SOLORIO, J
DATE: 10/19/88
SCALE:

Figure 18



AVE. GROUNDWATER EC (dS/m)
06/16/89

LEGEND

- ===== DIRT ROADS
- ○ OBSERVATION WELLS
- —— TILE DRAIN

Figure 19

REVISIONS:	
5/31/89	JG
12/28/89	

JMLord, Inc.

SJVDP FIELD W3

DRAWN BY: M.C.

DATE: 02/13/89

SCALE:

ECe levels higher than this in the bottom three feet of the profile. Cotton may start showing a yield reduction at an ECe of 7.7 dS/m. Field W-3 (cotton) has Ece levels lower than this throughout the soil profile. However, the salinity levels are much higher throughout the profile, except for the top foot, than would be acceptable for tomatoes or melons (crops in the current rotation).

Table 6 - Field B10-2 Average 1989 Soil EC and Boron

crop: tomatoes

Depth (ft.)	Avg. ECe (dS/m)	Avg. Boron (mg/l)
0-1	3.0	1.2
1-2	2.6	1.5
2-3	3.6	2.3
3-4	4.4	2.4
4-5	5.0	2.4
Averages	3.7	2.0
tolerance	2.5	4.0

Table 7 - Field P-1 Average 1989 Soil EC and Boron

crop: tomatoes

Depth (ft.)	Avg. ECe (dS/m)	Avg. Boron (mg/l)
0-1	2.2	1.8
1-2	2.4	2.1
2-3	3.4	3.3
3-4	4.8	4.7
4-5	5.5	5.1
Averages	3.4	3.4
tolerance	2.5	4.0

Table 8 - Field W-3 Average 1989 Soil EC and Boron

crop: cotton

Depth (ft.)	Avg. ECe (dS/m)	Avg. Boron (mg/l)
0-1	2.2	0.9
1-2	5.2	1.9
2-3	6.8	2.3
3-4	7.5	2.5
Averages	5.4	1.9
tolerance	7.7	6.0

E. Upflux and salt movement

1. Volume balance approach

SWAP/ET, an irrigation scheduling model, was used to forecast each seasonal irrigation as well as to determine daily ET values for DRAINMOD simulations. Three neutron probe sites were installed in each field to help monitor the soil moisture status. In each field two of the probe sites were 5 feet deep and the third was 8-9 feet deep. This information along with the depth of infiltrated irrigation water was used to calculate upflux. Upflux can be determined through a simple volume balance:

$$IR + UF - ET = dS$$

or

$$UF = dS + ET - IR$$

where:

IR = irrigation amount infiltrated for time interval
UF = upflux as previously defined for time interval
ET = crop water use and evaporation for time interval
dS = change in root zone moisture for time interval

A negative value calculated for upflux would indicate deep percolation. Seasonal amounts of upflux for the three neutron probe sites in each field were calculated and the results are presented in Table 9.

2. Field B10-2

As is indicated in Table 9 for Field B10-2, the average seasonal upflux exceeded the average seasonal deep percolation by 1.5 inches. In the Phase I report it was hypothesized that the salt balance could be maintained as long as there was a net positive downward movement of water that exceeded the leaching requirement. As indicated in Table 9 the leaching requirement for B10-2 is 1.5 inches. Based on these calculations the leaching requirement was not met. This would indicate that there may be some salinization of the root zone over this cropping season. It is normally a good management practice to not quite fill the soil profile on early season irrigations so potential rain may be put to beneficial use. However, when rain is short or non-existent as in this year, you run the chance of not being able to make up this amount later in the season. Not quite meeting this field's leaching requirement can be attributed to this.

Table 9 - Upflux Calculations

Field	Location	Upflux (in.)	Deep Percolation in.)	Net
B10-2	NP #1	3.7	-1.6	2.1
B10-2	NP #11	3.8	-1.5	2.3
B10-2	NP #24	2.8	-2.6	0.2
Averages		3.4	-1.9	1.5
P-1	NP #5	3.0	-4.3	-1.3
P-1	NP #15	1.9	-2.9	-1.0
P-1	NP #25	2.9	-4.1	-2.3
Averages		2.6	-3.8	-1.2
W-3	NP #6	1.5	-4.3	-2.8
W-3	NP #15	1.1	-6.6	-5.5
W-3	NP #20	1.3	-5.1	-3.8
Averages		1.3	-5.3	-4.0

B10-2 leaching requirement = 1.5 inches
P-1 leaching requirement = 1.9 inches
W-3 leaching requirement = 6.3 inches

$$LR = \frac{ECw}{5ECe - ECw}$$

$$ND = \frac{(ET\text{-}ef.rain)*LR}{(1 - LR)}$$

where

ND = Net yearly required depth for leaching

ECw = Electrical conductivity of the irrigation water.

ECe = Electrical conductivity of the soil extract at which yields start to decrease.

Figures 20a and 20b show how the soil salinity (ECe) and boron varied with time and depth (averaged over 18 sites). These figures also show three dates, January 1988, January 1989 and August 1989. For now only the January and August 1989 dates will be discussed because this portion of the analysis pertains primarily to this year's data. As indicated in the figure, from January '89 to August '89 there appeared to be a slight increase in soil salinity throughout the root zone except for the top foot. Boron levels are consistently higher for this same period. This pattern is what would be expected since it appears that the leaching requirement was not met during this period. Typically, tomatoes grown on the Westside experience severe reduction in the infiltration rate late in the season due to soil sealing. This is caused by a combination of soil type and a large number of furrow irrigations. This results in little or no leaching and sometimes under-irrigation. To make a full evaluation of the long term impact of DOS-IR Valves on salt balance, a cropping sequence will need to be evaluated.

3. Field P-1

Table 9 indicates that for P-1 the average seasonal deep percolation exceeded the upflux by 1.2 inches. Therefore, the leaching requirement of 1.9 inches was not quite met. Figures 21a and 21b show average ECe and boron levels for the five foot root zone (averaged over 21 sites). Although the leaching requirement was not quite met, there was virtually no change in the average ECe of the five foot soil profile between January and July. It was slightly lower, however, in the top three feet and somewhat higher in the bottom two feet. An average increase of 0.5 ppm boron per foot of soil was noted over the same time interval.

4. Field W-3

There was an average of 5.3 inches of deep percolation and 1.3 inches upflux. The leaching requirement of 6.3 inches was not satisfied. It should be noted that the leaching requirement was based on melons, the most salt sensitive crop in the rotation. There was a marked increase in salinity and boron levels this year. This was due primarily to the somewhat poor quality water that was used for irrigation. This field is part of a 640 acre tile drainage system that has no off-farm outlet. All tile drain water, in addition to some water inadvertently picked up from the partially plugged Westlands Water District collector system, is pumped into a large holding/evaporation pond. The water is recycled for irrigation by mixing it with District water. The EC of the mixture averaged 2.0 dS/m, approximately 3 to 4 times higher than the EC of District water.

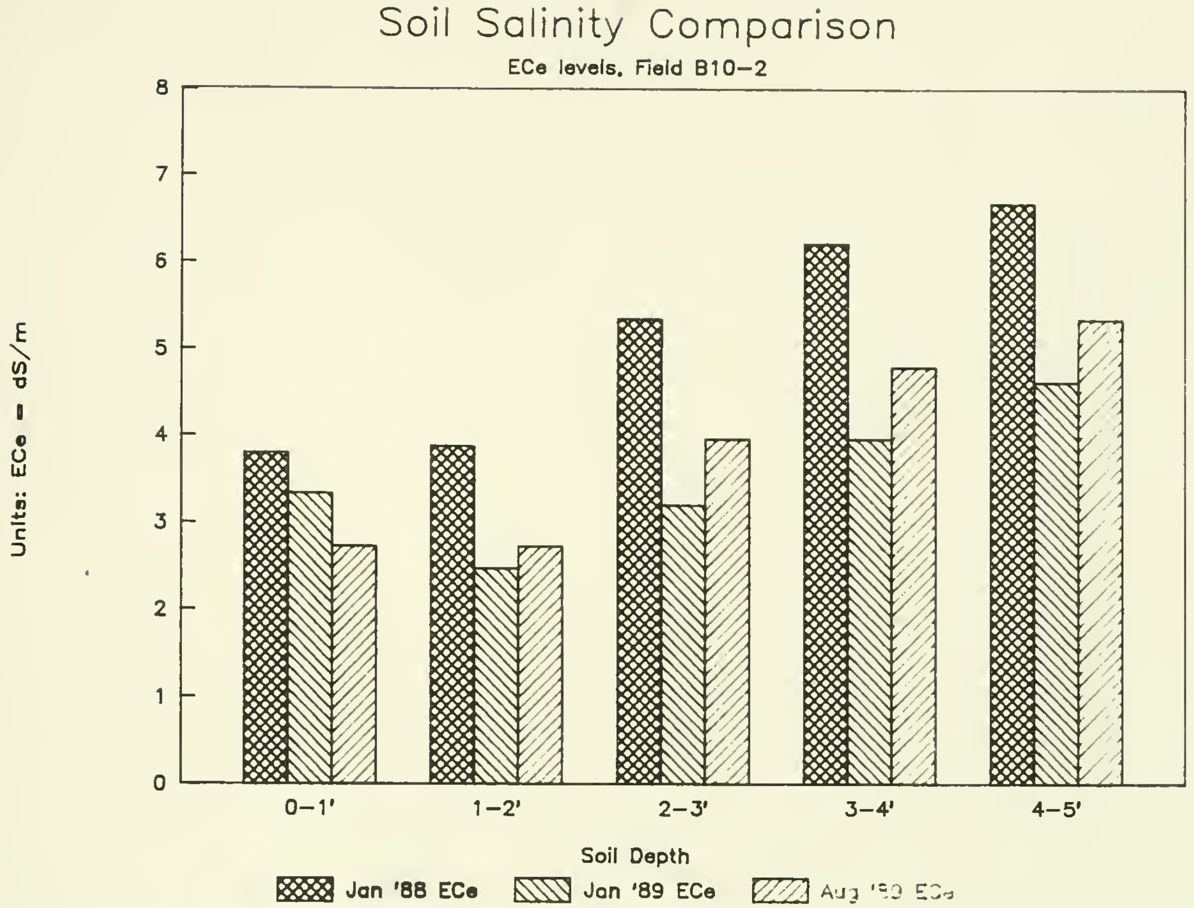


Figure 20a

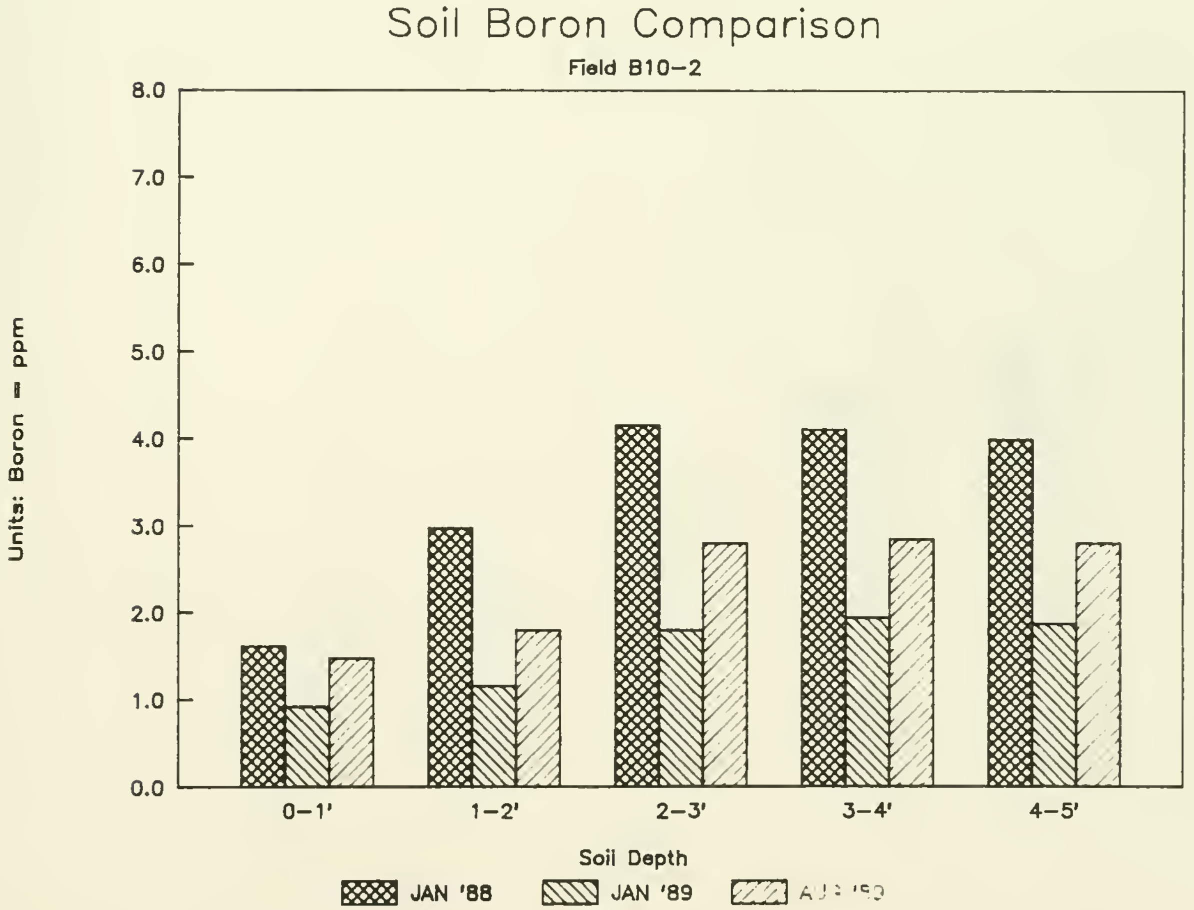


Figure 20b

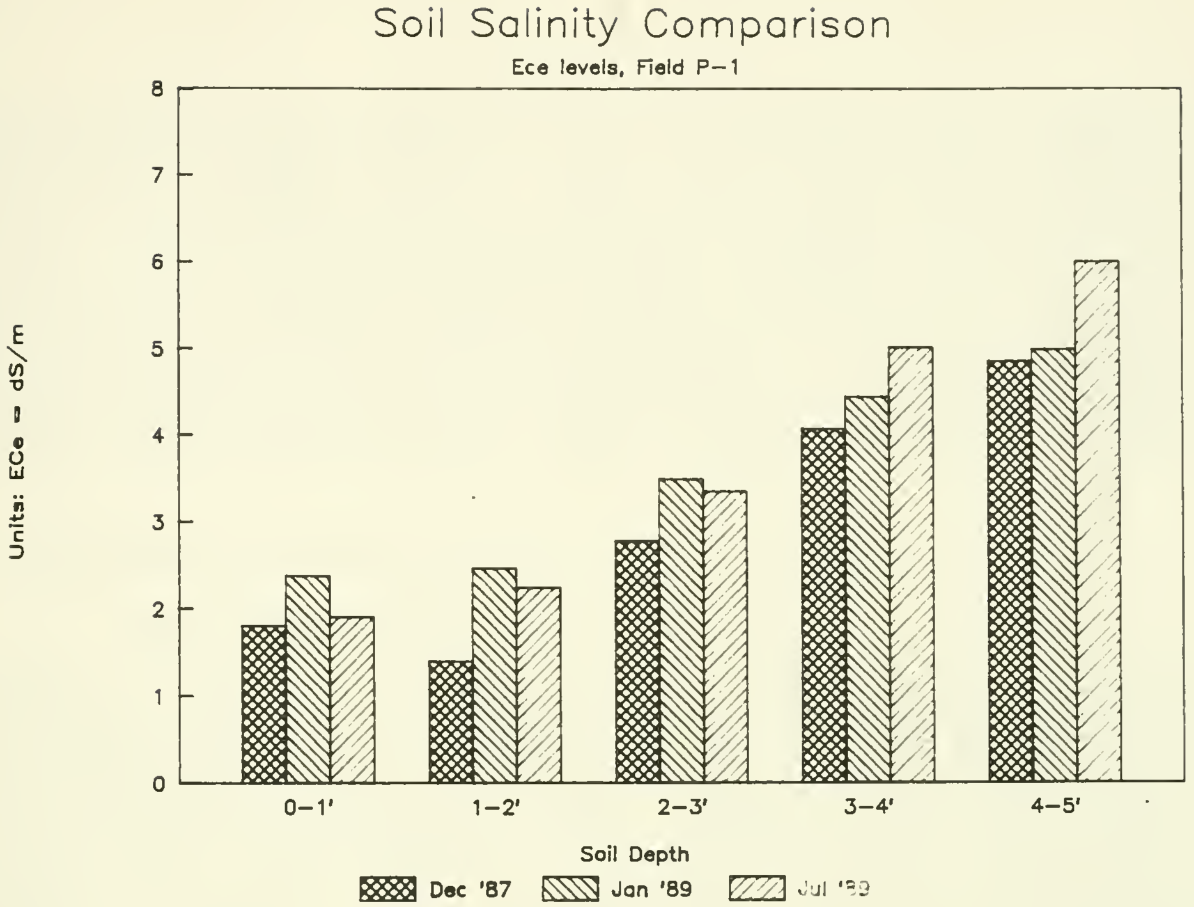


Figure 21a

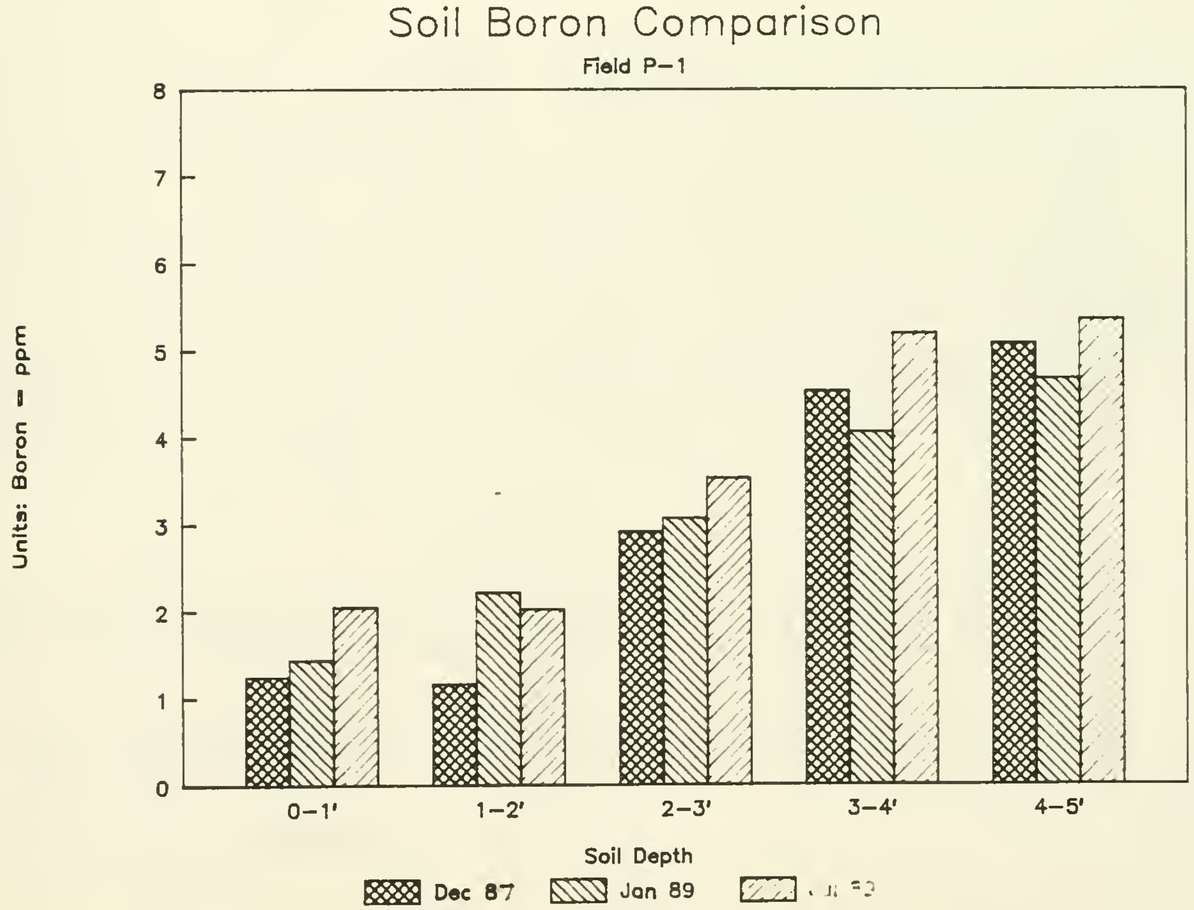


Figure 21b

As indicated in figure 22a the Soil Ec is greater than 5.0 dS/m for depths greater than one foot. This is an average of four composite groups of 12 samples each. These levels will reduce yields on future tomato and melon crops. This is a typical problem for tile drained fields within Westlands Water District. Environmental concerns have eliminated the Westlands drainage outlet and forced the plugging of the Westlands collector system. Until a District drain outlet is secured, salinity levels will continue increasing. Drainage management may prolong but cannot prevent the inevitable salinization of these areas. Alternatively, drainage management may be a way of keeping these lands in production until a drainage outlet is secured.

F. DRAINMOD simulations

1. Field simulations

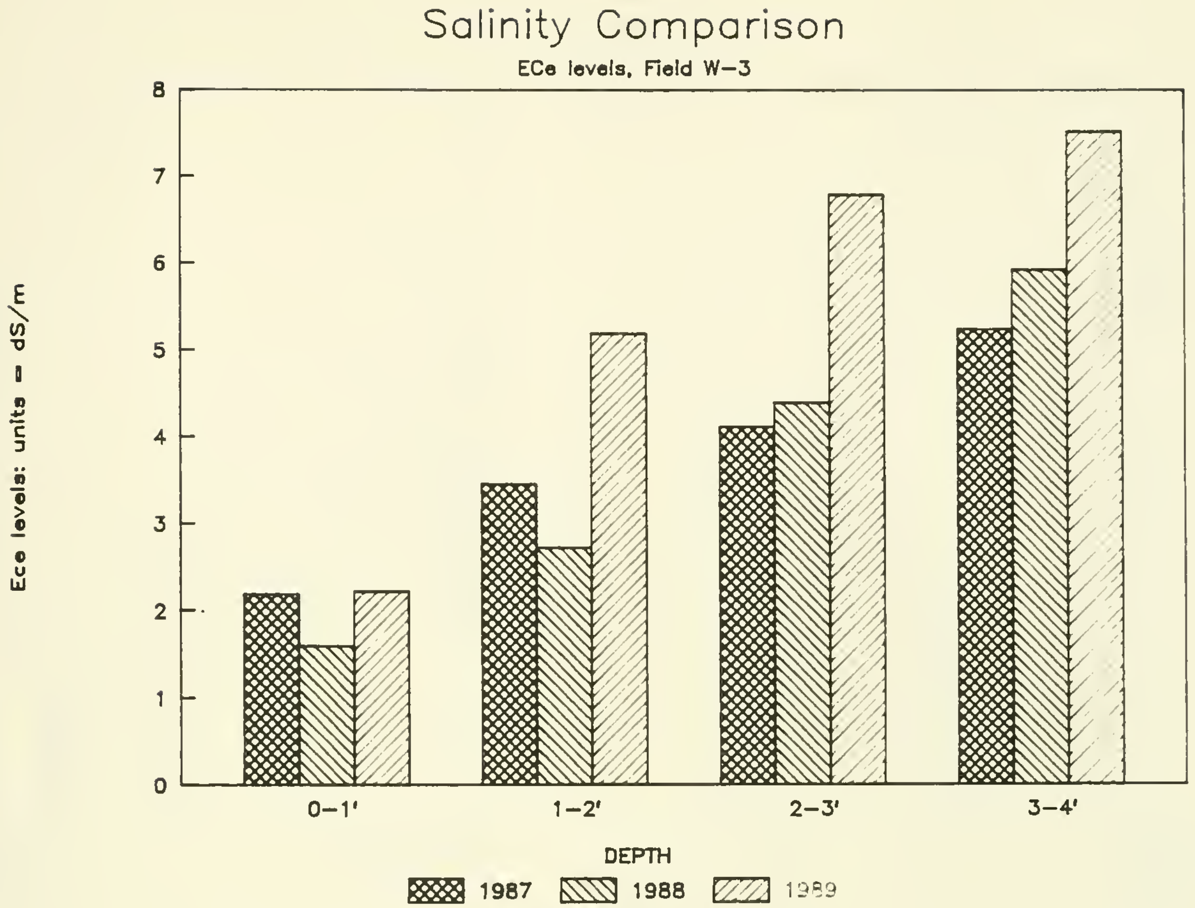
DRAINMOD 4.0 simulations were run for the cropping season for Fields B10-2 and P-1. Figure 23 shows the actual average water table depth versus the DRAINMOD simulation on Field B10-2 for the growing season. Version 4.0 allowed simulation for a partial year. This facilitated obtaining a good approximation to the actual average water table depth. Simulations run for longer time intervals than the actual growing season were not as successful because of external influences. The estimated upflux from DRAINMOD for B10-2 was 1.3 inches. The actual field estimated upflux was 3.4 inches.

Figure 24 shows the DRAINMOD simulation for Field P-1. As is indicated the predicted water table was significantly shallower than the actual water table. It was previously mentioned that version 4.0 allows input of lateral, vertical and down slope flow parameters. Figure 25 shows the same simulation but with the appropriate lateral flow parameters entered into the model. A relatively good prediction is obtained except between February 1, and mid March. This is due to the pre-irrigations of surrounding cotton fields, which had an obvious effect on the study field. Since surrounding irrigations cannot be modeled in this version of DRAINMOD, its use may be severely limited in this area. The DRAINMOD predicted upflux was 1.5 inches while the estimated field upflux was 2.6 inches.

2. DRAINMOD limitations

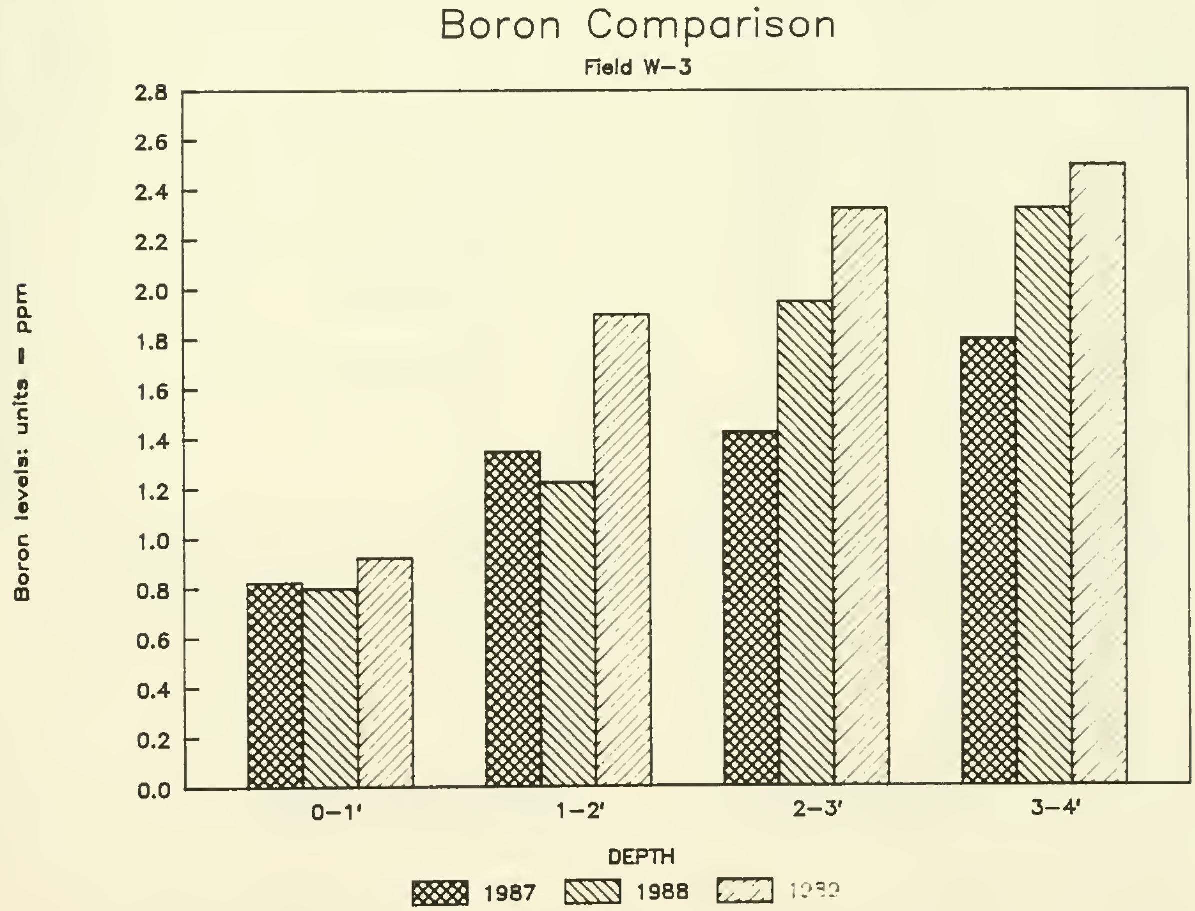
The following critique is based on data and experience obtained from this study and does not attempt to discredit or take away from the years of work that have been put into DRAINMOD.

As was mentioned earlier DRAINMOD 4.0 is significantly more user friendly and incorporates some added features. However, there are


Salinity Comparison

ECe levels, Field W-3

Figure 22a


Boron Comparison

Field W-3

Figure 22b

Figure 23

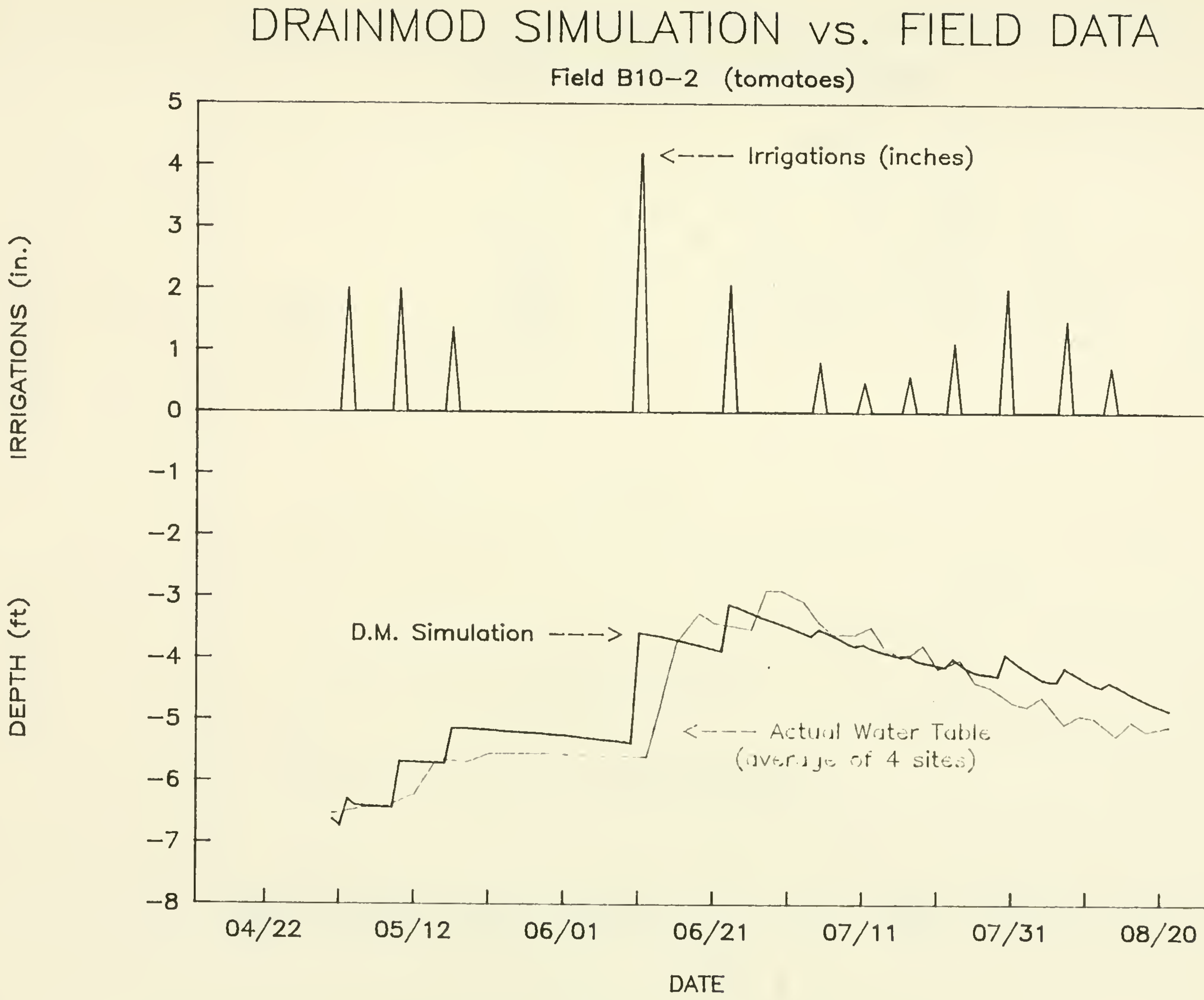

DRAINMOD SIMULATION vs. FIELD DATA
Field B10-2 (tomatoes)
<---- Irrigations (inches)
D.M. Simulation ---->
<---- Actual Water Table
(average of 4 sites)
IRRIGATIONS (in.)
DEPTH (ft)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
04/22
05/12
06/01
06/21
07/11
07/31
08/20
DATE

Figure 24

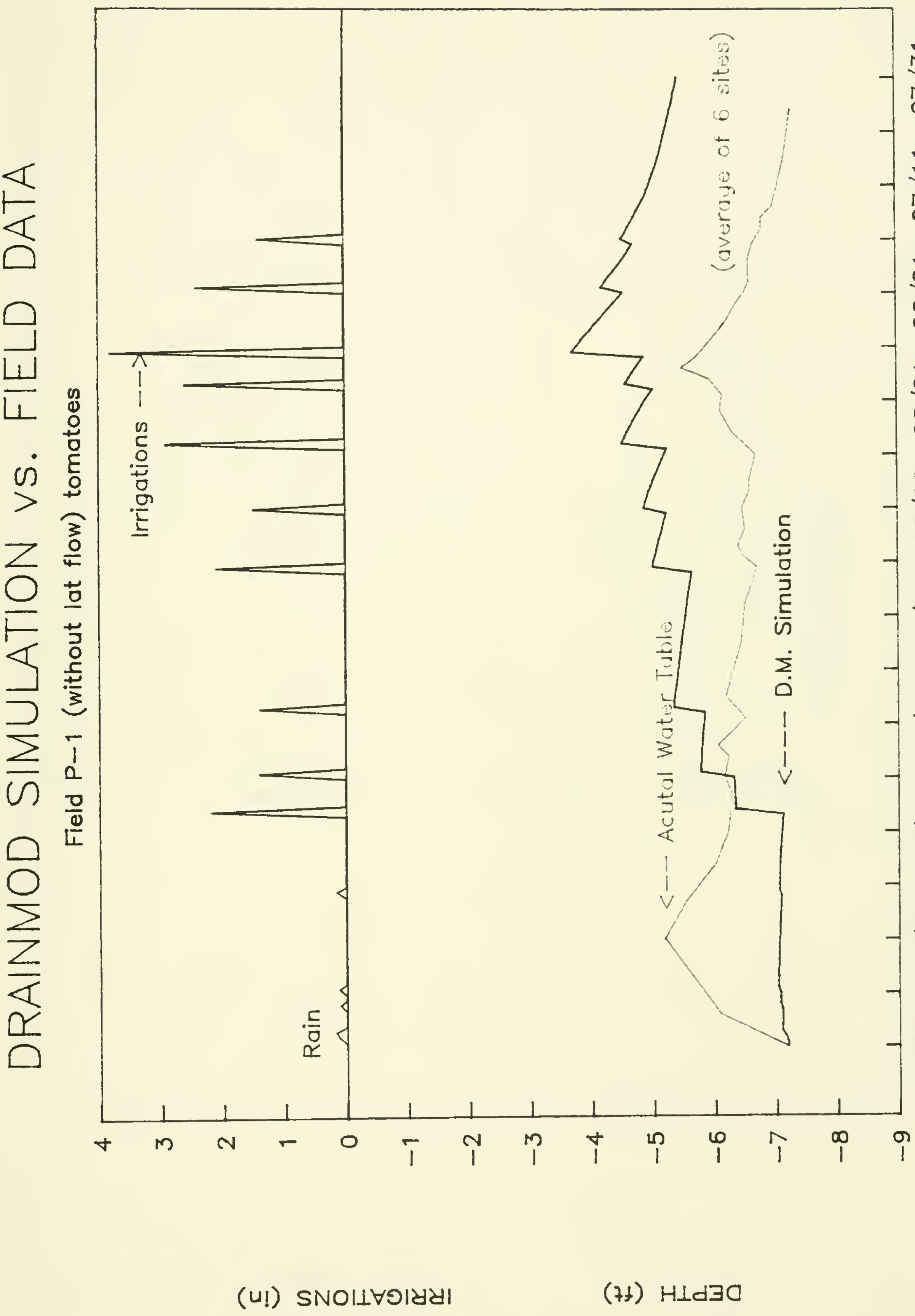
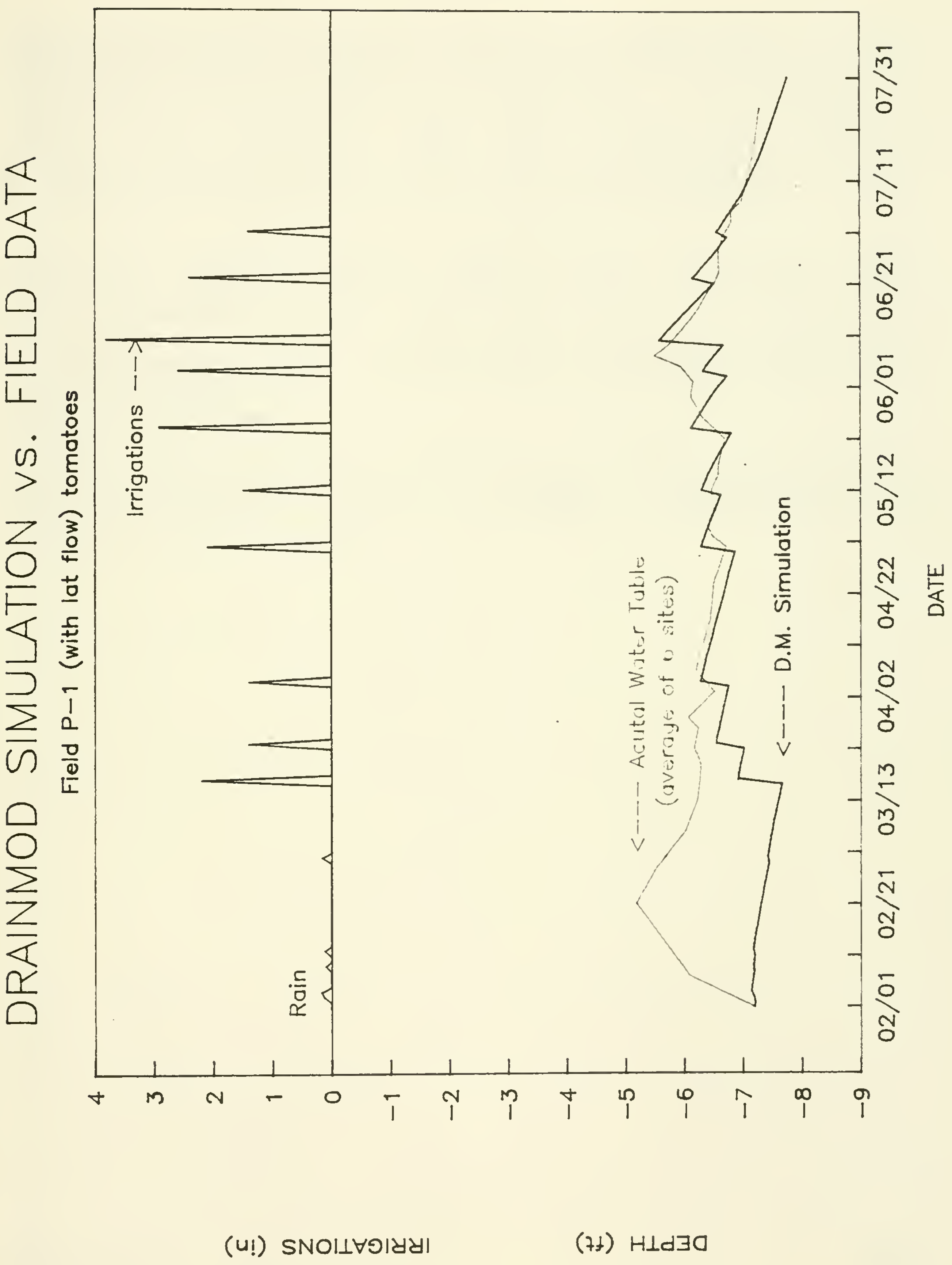

DRAINMOD SIMULATION VS. FIELD DATA
Field P-1 (without lat flow) tomatoes
Rain
Irrigations --->
<--- Acutal Water Table
(average of 6 sites)
<---- D.M. Simulation
IRRIGATIONS (in)
DEPTH (ft)
DATE
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
02/01
02/21
03/13
04/02
04/22
05/12
06/01
06/21
07/11
07/31

Figure 25


DRAINMOD SIMULATION VS. FIELD DATA
Field P-1 (with lat flow) tomatoes
Irrigations --->
Rain
<---- Acutal Water Table (average of 6 sites)
<---- D.M. Simulation
IRRIGATIONS (in)
DEPTH (ft)
DATE
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
02/01
02/21
03/13
04/02
04/22
05/12
06/01
06/21
07/11
07/31

still limitations that prevent it from becoming a practical daily management tool that could be easily used in conjunction with an irrigation scheduling program such as SWAP/ET. It was found that the shorter the simulation time interval the better DRAINMOD was able to track the water table. The shortest time interval available is one month. When scheduling irrigations under a production agriculture environment it is normal practice to update at least weekly, and tomatoes are generally updated twice a week.

The ET and irrigation/rainfall data cannot be entered interactively. DRAINMOD requires hourly irrigation/rainfall data. These data must be set up in external data files that can be created with an ASCII text editor. For this study we developed a "C" program that made it significantly easier to develop the irrigation/rainfall file. The developers of DRAINMOD have greatly improved the ease with which the rest of the required data files can be manipulated.

DRAINMOD cannot model the influence of a variable point source, such as an adjacent field being irrigated. It can model lateral flow out of and into a field but it assumes a constant head at the receiving sink (or source).

IV. 1988-89 COMBINED DATA ANALYSIS

A. Soils

Can the root zone salt balance be maintained while controlling the water table? This is one of the most important questions this study must address. It is also one of the most complex. Soil salinity levels normally vary during the season as well as year to year. There may be several different crops planted in a typical crop rotation. Each one has its own unique irrigation requirement and practices. All of these factors combine to make it difficult to determine long term salinity changes.

Figure 20a shows how the soil salinity levels (ECe) varied from January 1988 to August 1989 for Field B10-2. The January 1988 sample was taken before the DOS-IR Valves were installed. A one-way analysis of variance using an alpha of 0.05 and an "F test" was done to determine if there was a statistically significant difference between ECe levels over the three sampling dates. The critical F value was 3.180. This analysis was used because it allows comparison of the sample variability within groups (differences among samples from one sample date) with the variability among groups (differences between the three sampling dates). A separate analysis was done for each foot increment. The following hypothesis was tested:

$$H_0: A = B = C$$

against

$$H_a: \text{at least one inequality}$$

where;

A = sample mean for January '88

B = sample mean for January '89

C = sample mean for August '89

For each foot in the top three feet of the soil profile the null hypothesis (H0) was rejected so it was concluded that there were statistical differences between the three sampling dates. Alternatively stated, the samples came from populations with different means. There was no statistical difference for the four and five foot sample levels. When a rejected hypothesis indicates significance, Duncan's Multiple Range Test (alpha = 0.05) can be used to determine what samples differed. This will help determine if the DOS-IR Valves are the cause of the difference. Duncan's Test indicated in each case the January 1988 sampling date proved to be significantly different from the January and/or August 1989 sampling date. It also should be noted that no difference was indicated between the January 1989 and August 1989 sampling dates. From this information and Figure 20a the following can be concluded:

1. There was a significant decrease in salinity levels on Field B10-2 between January 1988 and January 1989. Since the DOS-IR Valves were installed in January 1989, this decrease has no relationship to the DOS-IR Valves.
2. Although Figure 20a indicates higher soil ECe's in all except the top foot, the above analysis indicates the increase is not significant.
3. These data show that under these particular field conditions the water table was controlled over the course of the study without significantly affecting the salt balance even though the leaching requirement was not quite met. It also shows that there is a significant variation in the season to season salt balance. This is probably due to different cropping and irrigation practices.

Figure 21 shows soil ECe and boron levels for Field P-1 on December 1987, January 1989 and July 1989. The same analysis of variance described earlier was run for Field P-1. It indicated that there were no differences in the soil salinity levels (ECe) for the three sample dates. This would again suggest that under the given field conditions the water table was controlled without adversely affecting the salt balance over the course of the study.

Figure 22 shows soil ECe and boron levels for Field W-3. Samples were taken in the fall of '87, '88 and '89. The graph indicates a disconcerting trend. Salinity and boron levels are significantly higher this year than in previous years. The analysis of variance described earlier was run and indicated a statistically significant difference throughout the profile over the indicated sampling dates. The salinity levels have risen an average of 20% per year over the last two years. At this rate the field could be put out of production except for only the most salt tolerant crops within five years. These data show that the salt balance is not being maintained. It should be noted that there was no actively controlled drainage program implemented on this field.

B. Water table quality

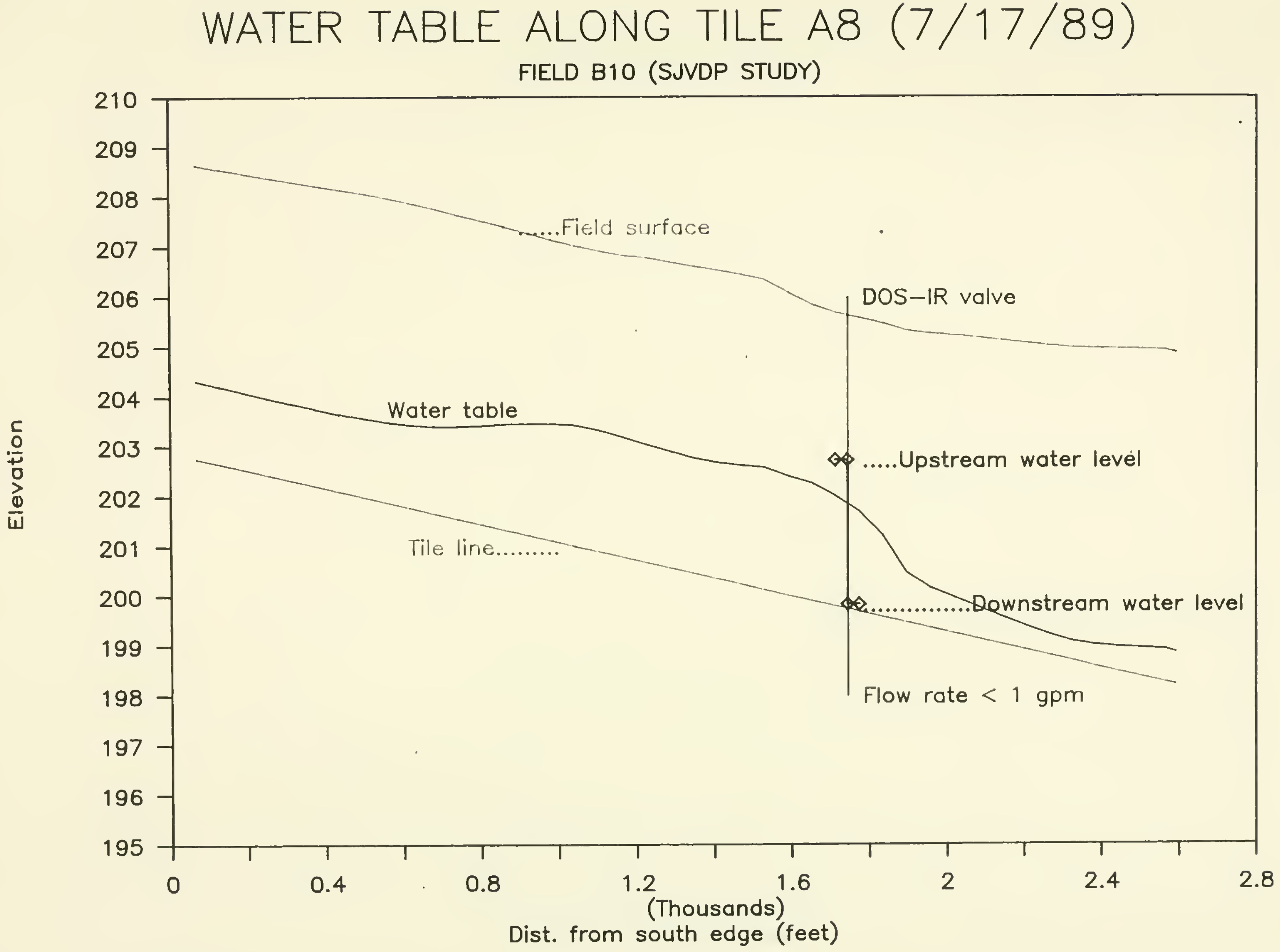
For Field B10-2 the average water table EC and boron levels reported in the Phase II Report for the 1988 season were 8.49 dS/m and 6.3 ppm, respectively. The average water table EC and boron levels for the 1989 cropping season were 7.53 dS/m (standard deviation of 3.0) and 4.2 ppm (standard deviation of 1.8), respectively. It is interesting to note that both of these levels are lower this year under controlled drainage than last year with uncontrolled drainage.

C. Effect of DOS-IR Valves on water table

As was discussed previously several more observation wells were installed around DOS-IR Valve A-8 in Field B10-2 in order to determine the valve's effect on the water table. Figures 26, 27, 28 and 29 show a cross-sectional area of Field B10-2 along tile line 8 for four different dates. The vertical line is a schematic representation of the DOS-IR Valve. If the valve were effective as a control device, one would expect some water table buildup upstream of the valve with a rapid drop across the valve. Each of the four figures demonstrates this, which indicates that the valves were affecting field water table depths. The upstream water level indicated in each figure shows the water depth as measured inside the upstream side of the valve. This reflects the hydrostatic head in the tile line and not the water table level. The line labeled "water table" is the actual water table depth as measured in the field by the grid of observation wells.

It was determined that although there was an obvious effect from the DOS-IR Valves on B10-2, there was also a large proportion of water bypassing the valve. It was estimated that 1/3 of tile effluent pumped off of this field actually flowed through the DOS-IR Valves. The remaining 2/3 of the water bypassed the valve. To effect maximum control of the water table, water bypass must be reduced. Methods of solving this problem will be discussed further in the installation criteria section of this report.

Figure 26



WATER TABLE ALONG TILE A8 (7/17/89)

FIELD B10 (SJVDP STUDY)

Figure 27

WATER TABLE ALONG TILE A8 (7/21/89)

FIELD B10 (SJVDP STUDY)

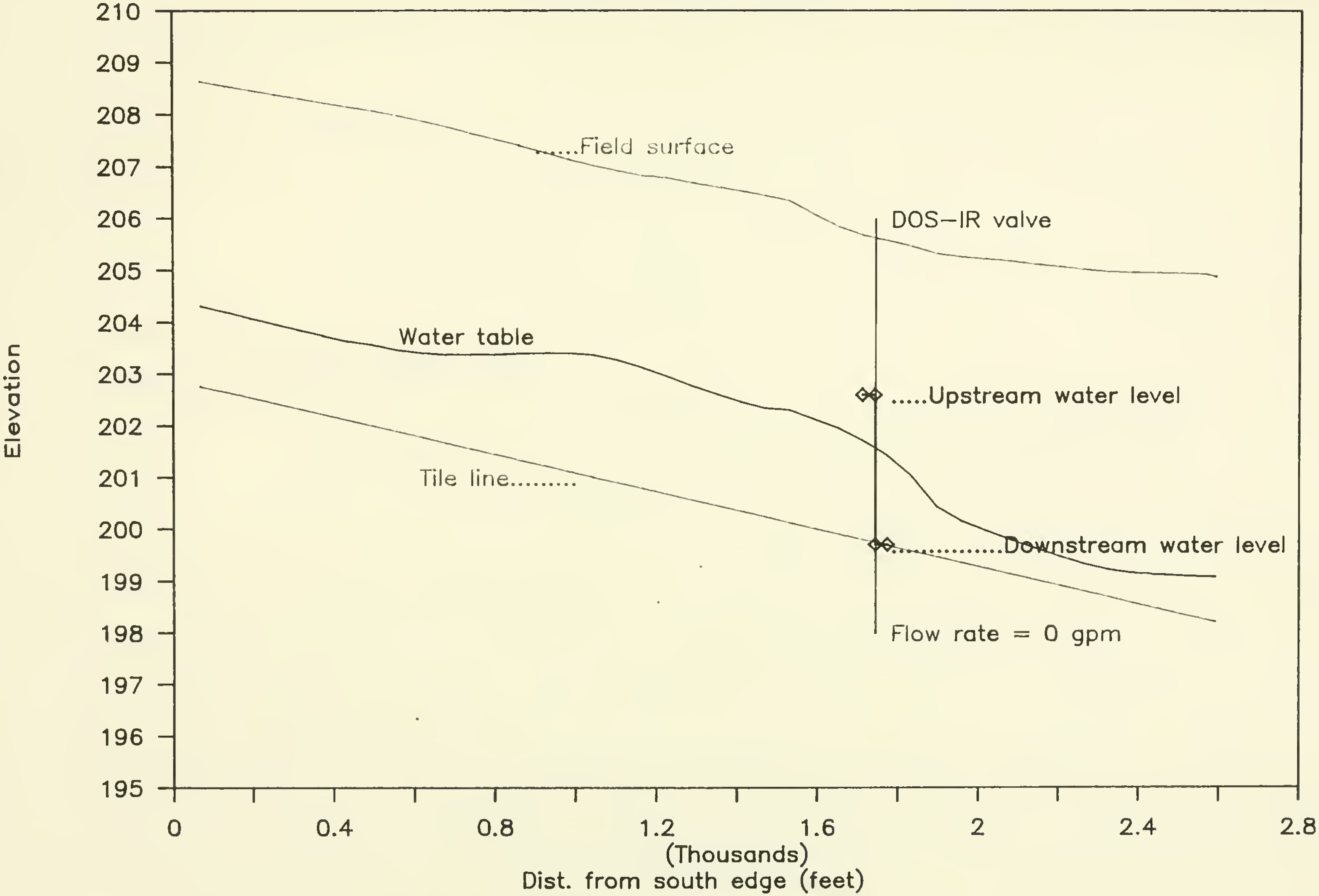


Figure 28

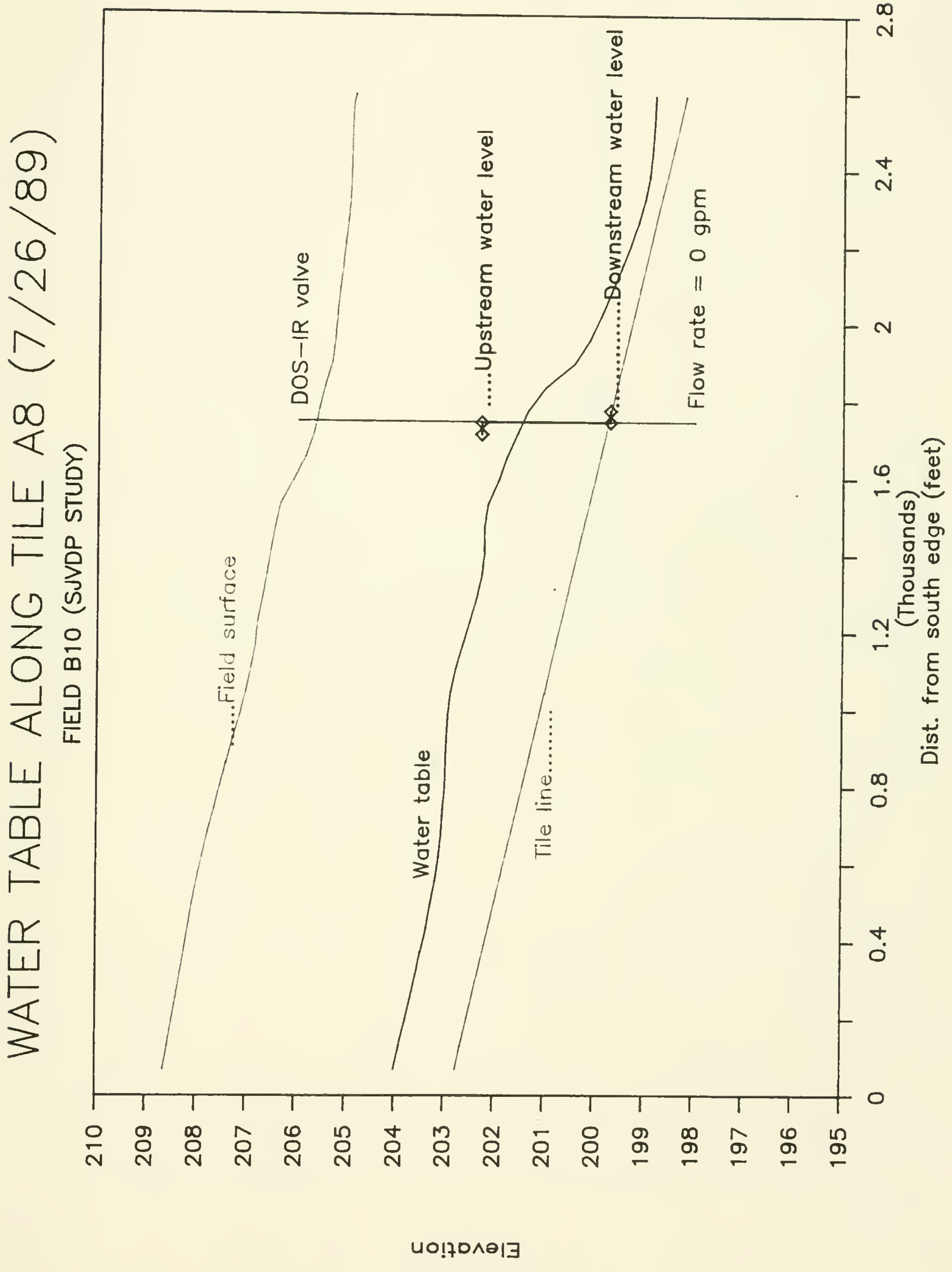
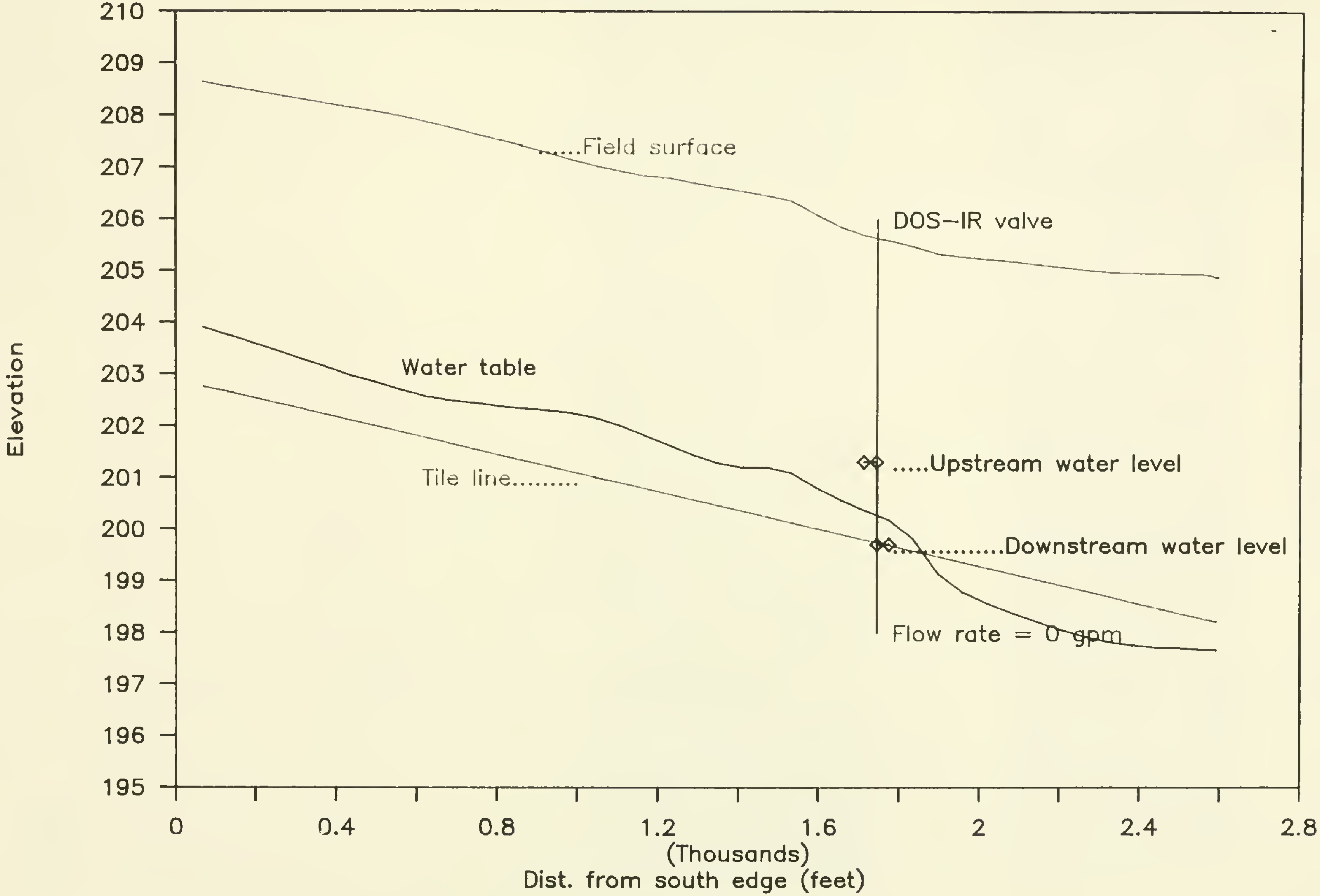

WATER TABLE ALONG TILE A8 (7/26/89)
FIELD B10 (SJVDP STUDY)
Field surface
Water table
Tile line
DOS-IR valve
Upstream water level
Downstream water level
Flow rate = 0 gpm
Elevation
210
209
208
207
206
205
204
203
202
201
200
199
198
197
196
195
0
0.4
0.8
1.2
1.6
2
2.4
2.8
(Thousands)
Dist. from south edge (feet)

Figure 29

WATER TABLE ALONG TILE A8 (8/21/89)

FIELD B10 (SJVDP STUDY)



V. LONG TERM IMPACT

A. Soil salinity

The two years of field data collected showed that the water table was controlled without a significant salinization of the root zone. It also indicated that there can be significant year to year variability in salinity levels based on cropping patterns and the accompanying irrigation management. The long term impact of water table control on soil salinity is still not clearly understood or fully defined. The data thus far indicate that the soil salt balance was not significantly affected by controlled drainage. To answer this question more fully a study such as this would have to last at least one typical cropping rotation, which is normally three to five years.

B. Drain tile effluent

One of the advantages of a DOS-IR Valve controlled tile system is that some of the peak discharges will be reduced. This can be important for future disposal facilities. Although a significant volume of water might bypass the control valves, the time for drain-out to occur is lengthened due to increased flow resistance produced by a closed or partially closed valve. The increased drain-out time gives a crop added opportunity to make use of upflux (as long as the water table is not hindering root growth) to satisfy its water requirements. Therefore, there is a reduction in the volume of tile effluent. Additionally, if quick drain-out is required for a leaching irrigation, the DOS-IR Valves may be opened for unrestricted tile system operation.

VI. MANAGEMENT GUIDELINES FOR DRAINAGE CONTROL

A. Field suitability for drainage control

Figure 30 shows a flow chart that aids in determining if a potential field is suitable for drainage control. In developing this chart it was assumed that the field was a typical, drained field on the west side of the San Joaquin Valley with tile depths of 6-7 feet and a field slope of 0-0.5%. Drains are assumed to have an adequate outlet and are not located on a barrier.

Each major component of the flow chart is discussed as follows. The numbers preceding the description correspond to those on the chart.

1. It must first be determined if there is a tile drainage system that appears to be in good condition. Initially, this is done through a grower interview. A grower will normally have an idea about how the system is operating. Questions to ask may include:

    a. How often does your sump run?

    b. Do you feel you currently have a high water table problem?

    c. Was there a significant change in the water table characteristics/depth the first season the tile system was installed?

    d. Has the water table depth increased, decreased or remained the same since tile installation?

    e. Was the whole tile system put in during one season or was it phased installation?

2. If step 1 indicates that the tile system is in good condition, the soils and cropping patterns must be examined. The soil texture, structure and hydraulic conductivity along with the crop rooting depth determine the spacing of the DOS-IR Valves along the tile line. The shallowest rooted crop in the rotation will determine the rooting depth.

    DOS-IR Valves installed in coarser textured soils with high hydraulic conductivity rates must be more closely spaced than those installed in finer textured soils with a low hydraulic conductivity. This is necessary to reduce the hydraulic gradient behind each valve in order to minimize the volume of water bypassing the valve.

FIELD SUITABILITY FLOW CHART

FOR INSTALLATION ON TYPICAL DRAINED 1/4 SECTION, 160 ACRES
TILE DEPTH 6.0–7.0 FEET
FIELD SLOPES 0–0.5%
DRAINS NOT ON BARRIER

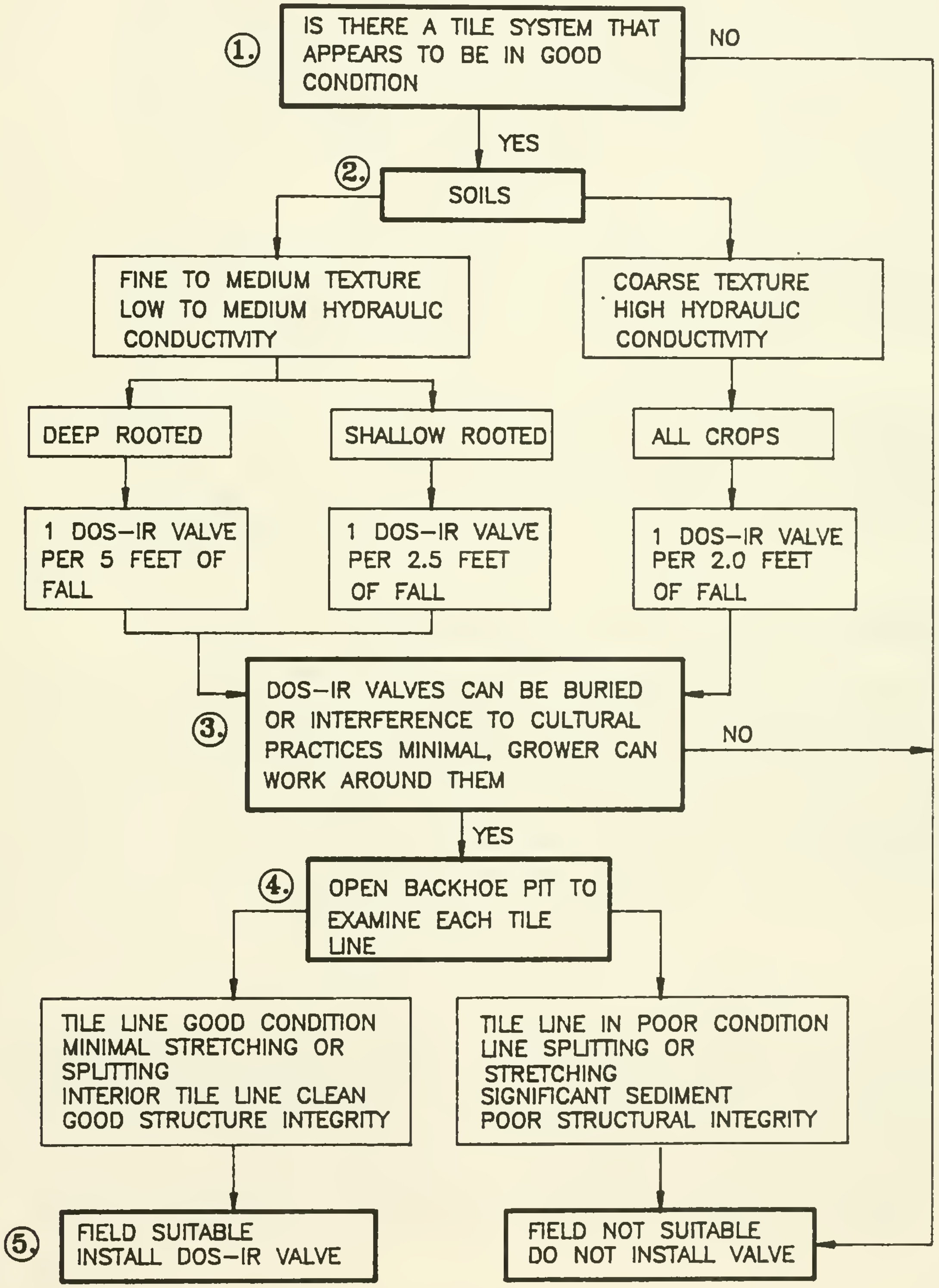

①
IS THERE A TILE SYSTEM THAT APPEARS TO BE IN GOOD CONDITION
NO
YES
②
SOILS
FINE TO MEDIUM TEXTURE LOW TO MEDIUM HYDRAULIC CONDUCTIVITY
COARSE TEXTURE HIGH HYDRAULIC CONDUCTIVITY
DEEP ROOTED
SHALLOW ROOTED
ALL CROPS
1 DOS–IR VALVE PER 5 FEET OF FALL
1 DOS–IR VALVE PER 2.5 FEET OF FALL
1 DOS–IR VALVE PER 2.0 FEET OF FALL
③
DOS–IR VALVES CAN BE BURIED OR INTERFERENCE TO CULTURAL PRACTICES MINIMAL, GROWER CAN WORK AROUND THEM
NO
YES
④
OPEN BACKHOE PIT TO EXAMINE EACH TILE LINE
TILE LINE GOOD CONDITION MINIMAL STRETCHING OR SPLITTING INTERIOR TILE LINE CLEAN GOOD STRUCTURE INTEGRITY
TILE LINE IN POOR CONDITION LINE SPLITTING OR STRETCHING SIGNIFICANT SEDIMENT POOR STRUCTURAL INTEGRITY
⑤
FIELD SUITABLE INSTALL DOS–IR VALVE
FIELD NOT SUITABLE DO NOT INSTALL VALVE

Figure 30

JMLord, Inc.

However, it may not be economically feasible to install an adequate number of DOS-IR Valves on fields with steeper slopes (0.4% - 0.5%) and coarse textured soils because of the close valve spacing required.

3. Any DOS-IR Valves in a field will interfere with cultural practices. Determining the field suitability due to interference will depend on the grower and the equipment used. If the grower is willing and able to work around the obstructions, then there should not be a problem. Under some conditions the valves may be buried. However, if the valves must be adjusted more than once or twice a season, then it is normally not practical to bury them.

4. If the field still appears to be a favorable choice, the next step is to open a backhoe pit so the project engineer may determine the condition of the tile lines. This step is necessary because it allows determination of field suitability before the DOS-IR Valves are purchased and a contractor is hired.

   The degree of splitting and stretching as well as the general tile structural integrity will be examined. The tile line interior should be examined. It should be relatively clean and free of sediment and debris. The valve should not be inserted if there is a significant problem.

5. If every step so far has given a positive result than the field is a good candidate for drainage control.

It has been estimated that there are approximately 50,000 acres of tile drainage systems in the San Luis Drainage Unit. It is difficult to estimate what percentage of these would be suitable for controlled drainage. However, based on experience approximately 80% of the fields we have examined and/or installed controlled drainage features on have shown good potential for successful controlled drainage implementation. Extrapolating this figure to all the drainage systems in the San Luis Drainage Unit would indicate a potential of 40,000 acres.

B. DOS-IR Valve installation criteria

To install the DOS-IR Valves it is recommended that a hydraulic excavator with a 5 foot, smooth lipped bucket be used. The trench should be dug perpendicular to the tile line. This aids in locating the tile and minimizes area exposed to possible damage. The installation of these valves is impossible if the drain is not operational or if the water table conditions are such that the drain is completely submerged. To reduce the possibility of trench collapse, trench walls should be cut at a 1:1 side slope.

Care must be exercised to ensure that the tile line is not damaged by the excavator. If the exact location is not known, a hand push rod can be used to locate the tile line. The excavator should expose the top of the gravel envelope. The remainder of the tile line must be exposed by hand.

The tile line should be cut approximately 3 inches away from each trench wall. Remove the section. Completely remove all gravel envelope material from the trench. This is important to help reduce water bypass around the valve.

The bottom of the DOS-IR Valve sits approximately 9 inches below the tile invert. The DOS-IR Valve should be placed one foot away from the downstream trench wall and in a slight depression, which will ensure that the tile line remains at original grade.

Connection of the valve to tile line requires three couplers. All connections must be made with non-perforated pipe with diameter equal to that of the tile line. Stainless steel wire should be used in conjunction with these couplers. Before final connections are made, a 6' by 10' sheet of plastic (2 mil or greater) should be used to line the upstream trench wall (10' edge along the horizontal) to act as an additional cutoff wall. A hole should be cut in the plastic approximately one foot from the longer edge and the upstream tile stub inserted. The plastic must be secured to the trench wall to keep it in place during back fill.

Once final connections are made, ensure that all new pipe has been placed on hand packed bed that conforms to previous tile grade. The first six inches of back fill must be done by hand and packed. This helps prevent crushing during back fill. Ensure that valve remains vertical and continue back fill process mechanically. Fill should not be dumped directly on tile line until at least three feet of cover are obtained.

C. Management

1. Monitoring

a. Soils -- Soil salinity levels should be monitored at least twice a year, once pre-season and once late season. At least 7, 0-5' profiles should be taken and analyzed in one foot increments independently. The soils data will help ensure that the field salt balance is maintained. If a problem is noticed, appropriate management decisions and actions can be made before major problems develop.

b. Tile flows -- Tile flows should be monitored every two weeks during the growing season. This indicates if the tile lines are flowing and can be used to judge the effectiveness of the tile lines. This level of monitoring can be reduced to once a month if everything proceeds as expected during the early part of the season.

c. Water table levels -- Water table levels should be monitored weekly between irrigations and twice a week during irrigations. There should be at least 20 observation wells in a typical quarter section. DOS-IR Valve weir settings are made to keep the water table below the root zone. If the water table is not tracked accurately, appropriate weir settings cannot be made. Again, this level of monitoring can be reduced as the season progresses if effective control has been established.

d. Water table quality -- Water quality samples should be taken from the observation wells twice during the season. A pre-season and a mid to late season sample is recommended. If the water table has particularly high salinity levels, the DOS-IR Valves may have to be set at a lower level than was previously planned, or may even have to be opened fully.

e. Irrigations -- Since the goal of the DOS-IR Valves is to enhance water table contribution to crop ET, irrigation amounts should be slightly more than or equal to the irrigation requirement. Therefore, it is imperative that the amount of water infiltrated on each irrigation be determined. This necessitates incorporating irrigation scheduling as well as measuring the volume of water applied and the volume that runs off the field.

2. DOS-IR Valve control

There are three different management scenarios that can be exercised to control the DOS-IR Valves. These are discussed as follows:

a. Responsive mode -- In the responsive mode a close watch is kept on the water table by weekly monitoring between irrigations and twice weekly monitoring during the irrigations. No drainage or irrigation scheduling models are used. DOS-IR Valves are set in response to the water table to keep it out of the active root zone but close enough so the plant can make use of upflux. This method has the advantage of being the easiest to implement, but its effectiveness depends on the speed to which the water table responds to changes in the DOS-IR Valves.

b. Predictive mode -- The predictive mode requires the conjunctive use of computer models such as DRAINMOD and SWAP/ET. SWAP/ET forecasts ET that is input into DRAINMOD by which DRAINMOD estimates the water table depth and upflux. SWAP/ET in turn can use the predicted upflux to estimate the next irrigation date. The current DOS-IR Valve weir setting and an estimated amount for the next irrigation may be input into DRAINMOD. It can then predict the water table depth after the irrigation. Several iterations can be run to determine the appropriate weir setting for the desired after irrigation water table depth. If an easy to operate and effective drainage model could be developed, this would be the ideal mode of operation, for it could minimize field work and be less expensive to implement.

   This method currently has severe limitations. The amount of water infiltrated on any irrigation is never accurately known before it occurs. The depth also varies spatially. This creates problems when trying to model several different locations in a field. DRAINMOD was found to take considerable data, time and effort to calibrate for each individual field and portions thereof and had the limitations discussed previously. It has been our experience that a reasonable DRAINMOD calibration takes one full season of field data. This makes it difficult to use the predictive mode the first season of controlled drainage with current available tools.

c. Combined mode -- The combined mode incorporates the best of both the responsive mode and the predictive modes. The same level of field monitoring as mentioned in the responsive mode is incorporated. However, DRAINMOD is used primarily to estimate upflux. Predicted upflux is then input to SWAP\ET as an irrigation by which SWAP\ET estimates the next irrigation. The valves are set based on response of the water table. This allows use of DRAINMOD over relatively short periods between irrigations. DRAINMOD has produced good results over short time periods.

3. Irrigation scheduling and system evaluations

Irrigation scheduling and irrigation system evaluations are an integral part of any controlled drainage management program. An irrigation schedule suggests the optimum date and amount of the next irrigation. The system evaluation determines how evenly and at what rate (pressurized systems) the system can apply water. An evaluation also may indicate how a system's distribution uniformity may be improved. If the recommendations can be incorporated, then deep percolation may be reduced. Combined, these two components can be used to ensure that the field is adequately irrigated in a timely manner throughout the season. This is especially important in a controlled drainage management program. If a crop is making use of upflux it will typically have a longer irrigation interval than a crop under non-water table conditions. Irrigation scheduling enables determination of next irrigation based on soil moisture and not based on past years' experience.

VII. CONCLUSIONS

A. Drainage control potential

1. DOS-IR Valves

DOS-IR Valves show good potential in controlling the water table. As was shown in the water table/tile line profiles (Figures 26-29) the DOS-IR Valves had an obvious effect on the water table upstream of the valves. The valve's effectiveness depends greatly on the installation procedure. This led to the development of installation criteria, which should be used as a guideline for future installations and drainage system designs. One major limitation of the effectiveness of the DOS-IR Valve on water table control is water bypass around the valve. Following the installation criteria will reduce this problem.

2. Crops

Over the course of this study the drainage control potential of fields planted to two major San Joaquin Valley crops, cotton and tomatoes, has been examined. Cotton fields show more drainage control potential than tomato fields because maintaining adequate soil moisture levels on cotton determines when the crop is to be irrigated. While soil moisture is equally important for tomatoes, late season irrigations frequently have to be scheduled to prevent bed cracking even though the total soil moisture may be wetter than the management allowed depletion. Tomato bed cracking can allow excess water to accumulate around the plant causing disease problems.

Part of cotton crop water use may be satisfied by deeper moisture pulled from the water table (upflux). The top two feet can be allowed to become relatively dry and soil cracking is not a problem. On tomatoes, although water use also may be partially satisfied by the water table, the top two feet cannot be allowed to become as dry as in cotton for reasons previously mentioned. This somewhat limits the effectiveness of drainage control on tomatoes. Similar limitations will be found on any crop that requires irrigation to prevent bed cracking and the resulting phytophthora.

3. Soils and topography

Most fields with tile drains in the San Joaquin Valley have soils that are suitable for drainage control. These soil are predominately loams to clay loams and on slopes less that 0.5%. Drainage control on sandier soil and steeper slopes may be possible but in most cases not practical due to the large number of DOS-IR Valves required, their interference to field operations and the associated cost. Fields should also be well graded with uniform slopes for maximum drainage control potential.

4. Salt balance

The field data collected thus far has shown that there was not an adverse significant effect on the field salt balance under a controlled drainage environment during the past two growing seasons. It should be stressed that it will take one or more cropping rotations before this can be determined with absolute certainty. However, based on experience gained during this study it appears that a soil salt balance can be maintained indefinitely when properly managed under a controlled drainage environment.

5. Economics

The cost of a typical controlled drainage program, as outlined earlier, is shown in Table 10. A capital recovery factor, (i.e., .1874) based on eight years and 10% interest, was applied to the DOS-IR Valves and related installation costs. The resulting yearly cost is $50 per acre. Table 11 shows the projected costs of a controlled drainage program in terms of costs per acre-foot of reduced drainage. The crop water table use as percent of ET for cotton and tomatoes is based on study field data. The data shown for alfalfa, sugar beets and melons are estimated. These data demonstrate that crops with higher crop water uses and longer seasons such as cotton, alfalfa, and sugar beets show more potential for drainage control than do crop with shorter seasons, such as tomatoes and melons.

It should be noted that this cost per acre-foot of reduced drainage water does not consider the agronomic benefits of improved water management nor the potential water savings typical of these types of programs.

B. Potential benefits

1. Reduced drainage flows

Drainage control using DOS-IR Valves has two main effects on tile drain flows. First, it can reduce the flows by developing improved opportunities for a crop to draw water from the water table. The reduction in drainage flows corresponds to the amount of water used by the crop. Second, it reduces peaks in tile discharge by spreading the flow over a longer period.

In order for there to be a reduction in the drain tile discharge (assuming minimal lateral or vertical flow losses), the crop must get part of its seasonal water use from the water table. Drainage control without this aspect will result in tile flow volumes

Table 10 -- Controlled Drainage Economic Spreadsheet

Based on typical 1/4 section (160 ac.) with 6 drain tile lines

ITEM DESCRIPTION	UNITS	NUMBER	COSTS	CRF	TOTAL	SUBTOTAL
Hardware installation costs						
1. DOS-IR Valves & connectors	ea	12	$420	0.1874	$944	
2. excavator rental costs/valve	ea	12	$140	0.1874	$315	
3. installation 2 technicians	days	2	$425	0.1874	$159	
4 Surveying	days	1	$640	0.1874	$120	$1,539 /year
CRF = Capital Recovery Factor, 8yrs @ 10%						
Field Work.						
1 Irrigation Scheduling & Fertility	seasons	1	$1,700	$1,700		
2 Irrigation evaluations	ea	1	$500	$500		
3 observation well installation + materials	ea	20	$55	$1,100		
4. Monitoring 8 times	ea	8	$100	$800		
5. Soil Salinity sampling	days	1	$350	$350		
6. Soil Salinity Lab analysis 7, 0-5's	sample	35	$30	$1,050	$5,500 /year	
Engineering.						
1 Engineering	days	2	$500	$1,000	$1,000 /year	

TOTAL:	$8,039 /year
Cost/acre	$50 /year

Table 11 -- Projected Costs of Controlled Drainage Program Based on Crop

(Using management costs of $50/acre)

--- *Values based on field data except as noted*

					Saved irrigation water			Reduced drainage discharge				NET
	w/DV	wo/DV	DIFF	CROP ET	INCHES	FCW	YWS	INCHES	AC-Ft	COST/AF	WS	COST/AF
cotton	35%	10%	0.25	27	6.7	$55	$31	6.7	84	$95	$31	$64
tomatoes	15%	*5%	0.1	22	2.2	$55	$10	2.2	28	$292	$10	$282

*estimated--no field data available

-- *All values listed below are projections. No controlled drainage data are available for crops listed.*

					Saved irrigation water			Reduced drainage discharge				NET
	w/DV	wo/DV	DIFF	CROP ET	INCHES	FCW	YWS	INCHES	AC-Ft	COST/AF	WS	COST/AF
alfalfa	30%	15%	0.15	60	9.0	$55	$41	9.0	113	$71	$41	$30
sugar beets	35%	15%	0.2	33	6.6	$55	$30	6.6	83	$97	$30	$67
melons	15%	5%	0.1	13	1.3	$55	$6	1.3	16	$495	$6	$489

Column Heading Descriptions:

w/DV = Crop use as percent of ET with Drainage Control
wo/DV = Crop use as percent of ET without Drainage Control.
DIFF = Difference between the two previous columns.
CROP ET = Evapotranspiration for the crop indicated
INCHES = Inches of water
FCW = Approximate non-subsidized cost Central Valley Project water.
YWS = Yearly Water Savings in dollars (total)
AC-Ft = Volume of reduced drainage per season based on 150 acres.
COST/AF = Estimated cost of controlled drainage per ac-ft. program costs/volume of drainage reduction
WS = Water savings from reduction in applied water
NET COST/AF = Net cost/ac-ft of controlled drainage program including savings from a reduction in applied irrigation water

similar to those under a non-controlled environment. However, the peak discharges should be reduced and the flow spread out over alonger time interval. Under a minimal or non-crop water use situation, drainage control would still be valuable because it could produce more constant tile flow rates for future treatment or management facilities. This would result in cost savings for the construction of handling and disposal facilities due to smaller capacities.

2. Water savings

When a crop receives part of its seasonal water use from upflux, the amount of irrigation water that must be applied can be reduced. Over the course of the study for controlled drainage conditions on tomatoes, approximately 15% of the seasonal crop water use came from upflux. For controlled drainage conditions on cotton 35% of the seasonal crop water use came from upflux. However, for a substantial portion of this savings to be realized, irrigations must be scheduled accurately and the appropriate amounts uniformly applied.

C. Future drainage control

The future should produce more accurate drainage, salinity and irrigation scheduling models that will be easier to use and enable more computer simulation of field conditions. More uniform and efficient methods of water application also may become cost effective. All these factors will reduce the field monitoring requirement that is currently necessary for appropriately managing a crop in a controlled drainage environment. These models must be written so they are practical to use in a production agricultural environment. Many models developed today are research tools and are impractical for day to day use.

The DOS-IR Valve, or a similar concept will help drainage treatment or disposal facilities to process drain effluent more efficiently. This will be accomplished by reducing the peak tile discharges that would normally occur during pre-irrigations.

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